Coupling coefficient for TEA CO_2 laser propulsion with variable pulse repetition rate

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Because pulse repetition rate affected directly the momentum coupling coefficient of transversely excited atmospheric (TEA) CO_2 laser propulsion, a double pulse trigger, controlling high voltage switch of laser excitation circuit, was designed. The pulse interval ranged between 5 and 100 ms. The momentum coupling coefficient for air-breathing mode laser propulsion was studied experimentally. It was found that the momentum coupling coefficient decreased with the pulse repetition rate increasing.

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Rocket propulsion by laser was firstly put forward by Kantrowitz in 1972[1]. By this means, the mini satellite or aircraft can be sent to a definitive orbit. With the development of laser and space navigation technologies, more and more countries began to attach importance to the application of laser propulsion. On October 2, 2000, Myrabo used a pulse CO_2 laser to propel the 50-g craft to an altitude of 71 m in 12.7-s, the pulse duration of the laser is 30 μs, the single pulse energy is 1 kJ, and the repetition rate is 10 Hz[2]. In China, the craft was launched successfully to an altitude of more than 1 m and the effect of air pressure on the coupling coefficient of laser propulsion was studied[3−5]. To investigate the relation between the laser pulse repetition rate and the coupling coefficient, we designed a double-pulse trigger to simulate different operating repetition rates of the transversely excited atmospheric (TEA) CO_2 laser. The effect of the laser pulse repetition rate on the coupling coefficient was explored through that, and preliminary experimental data was acquired to select optimal laser pulse repetition rate for propulsion.

For laser propulsion, the influence of the laser pulse repetition rate on the momentum coupling coefficient is an important research focus. Researchers paid much attention to it and made a great effort to seek a high repetition rate laser in the past years. But for the high energy pulse laser, it is difficult to run steadily with high variable repetition rate. Moreover, once high frequency pulse sequences go wrong, the error will complex the analysis of result. Also, the individual effect of each pulse will be confused. However, distinguishing the individual effect is the key to the study.

The double pulses are the minimum pulse sequence, and the repetition rate of pulse sequence depends on the interval of the two adjacent pulses. Consequently, double pulse laser can simulate the high repetition rate pulse laser. Adjusting the interval of the double pulses can control the pulse-repetition rate accurately. By this means, we can explore the effect of variable laser pulse repetition rate and easily distinguish the effect of each pulse on the propulsion. So we designed a set of double-pulse generating device to launch two successive pulses with controllable interval to trigger TEA CO_2 laser. This idea made the effect of pulse repetition rate on the propulsion simple and clear. The schematic diagram of the double-pulse TEA CO_2 laser is shown in Fig. 1.

The trigger signals were divided into two branches, one ignited high voltage trigger directly, the other ignited it again in some delay time. Thus the double discharges generated the double pulses.

The experimental setup is shown in Fig. 2. The laser energy is up to 15-J per pulse with full width at 10% maximum of 3 μs and full width at half maximum (FWHM) of 200 ns. The laser was ignited by double-pulse trigger, the output beam was sampled separately by two sampling plates. The sampling signals were detected by photon drag detector and the laser pulse waveform was recorded by oscilloscope 1 (OS1). The laser energy meter (LEM) measured its energy. The beam was incident on the parabolic craft then reflected, focused, and made the air breakdown. Air detonation wave supported by laser kept propelling the craft to slide on the air guide track. Oscilloscope 2 (OS2) was used to measure the time and position of the craft using U-baffle below craft and the

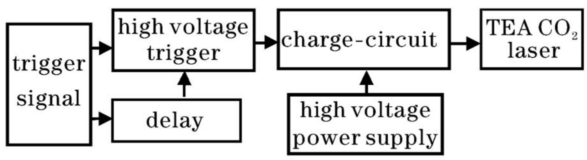

Fig. 1. Schematic diagram of double pulse TEA CO_2 laser.

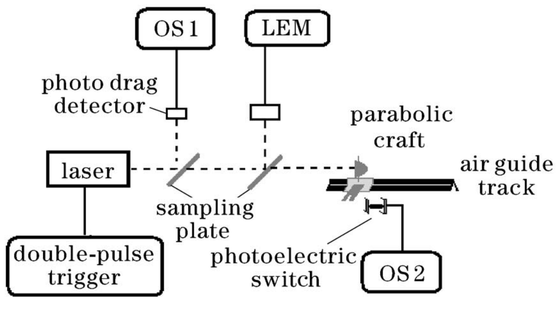

Fig. 2. Experimental setup.

array of photoelectric switch, so that the velocity and the momentum coupling coefficients of the craft could be calculated. In the experiment, the single laser pulse output energy is 13 J.

Neglecting the air resisting force and the frictional force of system, the impulse of craft can be written as

$$p = mv = m\frac{l}{\Delta t}, \quad (1)$$

where p is the momentum imparted by double pulses and l is the width of the U-baffle, Δt is the minimal interval for the baffle passing the array of the photoelectric switch, m is the total mass of the craft and the gliding block.

Actually, the value of coupling coefficient imparted by the first pulse differs from that by the second pulse, thereby a mean coupling coefficient $C_{\rm m}$ for the double pulses is defined as the ratio of the imparted impulse to the double laser pulse energy

$$C_{\rm m} = \frac{p}{E} = \frac{1}{2E_0}\frac{ml}{\Delta t}, \quad (2)$$

where E_0 is the energy of the single laser pulse.

The measured data and the fitting curve of the relation between the coupling coefficient and the pulse repetition rate is shown in Fig. 3.

Figure 3 indicates that under the condition of laser single pulse energy of 13 J, the coupling coefficient decreases with increasing the pulse repetition rate. From 0 to 50 Hz, the coupling coefficient is up to 10.5×10^{-5} N/W, and 8.5×10^{-5} N/W from 50 to 200 Hz. Apparently, there is a knee point at pulse repetition ratio of 50 Hz.

One should be curious to deduce the partition between the first and the second pulses to the aircraft's momentum. To analyze the ratio of the coupling coefficient for each pulse to the total coupling coefficient for the double pulses, the coupling coefficient of craft imparted by the single pulse was measured and calculated.

Figure 4 indicates that the ratio of the coupling coefficient imparted by the second pulse decreases sharply with the increase of frequency of the pulse laser and the ratio of the coupling coefficient imparted by the first pulse increases quickly. According to our preliminary analysis, the first laser pulse propels the craft to overcome the breakout friction, while the second pulse overcomes only friction. It is well known that the breakout friction is much greater than the friction. The

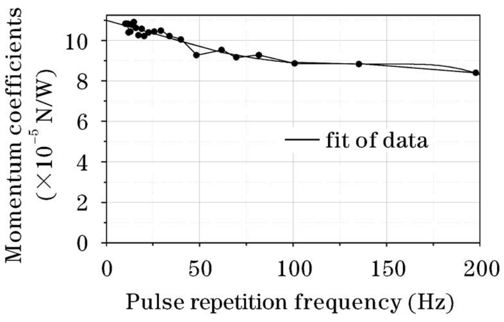

Fig. 3. Momentum coefficients versus pulse repetition rate.

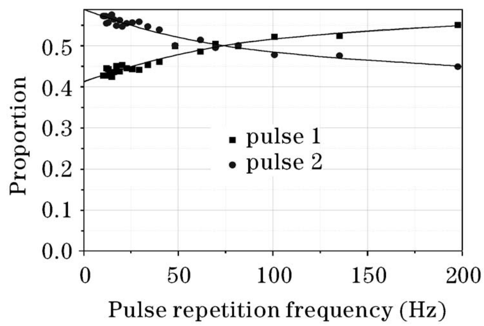

Fig. 4. Ratio of the coupling coefficient for each pulse.

momentum caused by the second pulse is more than the first. So for low repetition rate, the second pulse's contribution to the momentum coupling coefficient is greater than the first pulse's. But when laser pulse repetition rate augments, the effect of the first pulse on the coupling coefficient cannot be ignored any more since the ratio of the coupling coefficient imparted by the second pulse becomes less and less.

As for the air-breathing mode propulsion of repetition rate TEA CO_2 laser, the physical process can be simplified as follows: firstly, the laser beam was reflected by the parabolic craft and focused to make air breakdown, then laser supported detonation wave (LSDW) propelled the craft to move. When the high temperature air in the parabolic dish expanded, most of them would escape from the craft. Finally, with the expansion of the LSDW, the pressure difference between inner and outer of craft caused the air around the craft to flow into the craft. Apparently, because the air as the propellant would not be supplied enough for the high pulse repetition rate, the effect of the propulsion would be weaken.

It was found in the experiment of the TEA CO_2 laser (200 ns, 13 J) propulsion with air-breathing mode, coupling coefficient decreased sharply with the increase of the pulse laser repetition rate. There is a knee point at the laser pulse repetition ratio of 50 Hz. And it was also found that with the increase of the pulse laser repetition frequency, the proportion of the first pulse coupling coefficient to the total coupling coefficient became greater than that of the second pulse.

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References

1. A. Kantrowitz, Astronautics and Aeronautics **10,** 74 (1972).
2. L. N. Myrabo, in *Proceedings of First International Symposium on Beamed Energy Propulsion* 49 (2003).
3. Y. Zheng, P. Gong, R. Tan, Z. Tang, C. Ke, J. Cai, C. Wan, X. Hu, Y. Yu, S. Liu, J. Wu, G. Zheng, J. Zhou, and Y. Lu, Chin. J. Lasers (in Chinese) **32,** 889 (2005).
4. Z. Tang, P. Gong, X. Hu, J. Cai, R. Tan, Y. Lu, and C. Ke, in *Proceedings of Second International Symposium on Beamed Energy Propulsion* 23 (2004).
5. P. Gong, R. Tan, Z. Tang, Y. Zheng, J. Cai, C. Ke, X. Hu, C. Wan, Y. Yu, S. Liu, J. Wu, J. Zhou, Y. Lu, and G. Zheng, Chin. Opt. Lett. **2,** 538 (2004).