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Shadowgraphy of Shock Wave Induced by Double Pulse Technique

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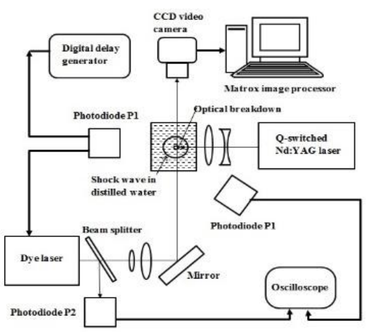
Graphical abstract



Abstract

High-speed videography based on double pulse of Nd:YAG laser to capture dynamic expansion of shock wave is reported. A Q-switched Nd:YAG laser was employed as an input signal and disturbance source. Nitrodye laser was utilized as a flash. The shock wave generation was recorded via CCD video camera. Synchronization is organized associated with a digital delay generator. Nd:YAG laser was focused to generate an optical breakdown in distilled water. Double pulses were generated within the interval of one second. The first pulse of Nd:YAG laser was used to trigger the dye laser and the second pulse to generate shock wave. Manipulation of delay times allow to freeze the dynamic expansion of shock wave. The double pulse technique is appropriated for laser system with the absence of external trigger unit. Lack of electronic failure is the advantage offer by the double pulse technique.

Keywords: High-speed videography, double pulse, Nd:YAG laser, Nitro-dye laser, synchronization, shock wave, sound speed

Abstrak

Videografi kelajuan tinggi berdasarkan dua nadi Nd:YAG laser untuk menangkap perkembangan dinamik gelombang kejutan dilaporkan. Pensuisan-Q Nd:YAG laser telah bertindaksebagai isyarat input dan sumber gangguan. Nitrodye laser telah digunakan sebagai flash. Generasi gelombang kejutan direkodkan melalui kamera video CCD. Penyegerakan dianjurkan berkaitan dengan penjana kelewatan digital. Nd:YAG laser ditumpukan untuk menjana pecahan optik di dalam air suling. Denyutan Double telah dijana dalam tempoh satu kedua. Nadi pertamaNd: YAG laser telah digunakan untuk mencetuskan laser pewarna dan nadi kedua untuk menjana gelombang kejutan. Manipulasi masa tunda membenarkan untuk membekukan perkembangan dinamik gelombang kejutan. Teknik nadi dua diperuntukkan bagi sistem laser dengan ketiadaan unit pencetus luaran. Kekurangan kegagalan elektronik adalah tawaran kelebihan oleh teknik denyut dua.

Kata kunci: Videografi kelajuan tinggi, nadi double, Nd:YAG laser, Nitro-pewarna laser, penyegerakan, gelombang kejutan, kelajuan bunyi

1.0 INTRODUCTION

The advancement of high-speed photography has always been crucial to detailed analyses of shock and detonation effects [1] and other application like laser ablation in liquid [2]. Shock waves play an important roles in modern physics and engineering [3-6], military operations [7], materials processing [8-11] and medicine [12, 13]. Nowadays, high-speed videography equipment is combined with some classical visualization methods to image shock waves from explosions in more realistic environments. This allows the development and progress of these wave fronts to be captured on a scale that has not been possible in the past. An optical method that works extremely well for visualizing shock waves is including shadowgraph [14, 15], Schlieren [16] and interferometry [17-20].

High-speed photography can be used to capture some spectacular images, but the technique requires a great deal of preparation, precision and patience. There are a few technical challenges need to overcome, particularly when it comes for timing, which involve much on electronic and computer programing for synchronization. When dealing with electronic it always associated with external trigger unit. Not all lasers are provided with external trigger. The absent of external trigger can be overcome by using double pulse technique. In this present paper, a high-speed vediography system was developed based on double pulse of Nd:YAG laser technique. The procedure to capture a dynamic expansion of shock wave in distilled water is discussed in detail.

2.0 EXPERIMENTAL

A Photonic PRA Nitro-mites Nitrogen Model LN 102C was used to pump a dye laser module, LN2C. The organic dye coumarin-500 was used as a gain medium. The concentration of dye was 1 x 10^{-2} mole and ethanol was used as a solvent. A tuneable output is produced with wavelength in the range of 473–547 nm. The pulse duration for the dye laser is 300 ps. The output energy is less than 12 mJ per pulse. The laser can be triggered from external using input pulse of 5 V. The dye laser was expanded by using two lenses; one is an objective microscope with focal length f_1, of 7 mm and the other is camera lens with focal length f_2 of 70 mm. Hence the magnification is achieved up to 10 times.

A PRO Q-switched Nd:YAG laser manufacture from China was used as double functions. It work at fundamental wavelength of 1064 nm, pulse duration of 10 ns and maximum energy of 1 J. Conducted in repetitive mode with frequency of 1 Hz. The beam spot size is 2 mm in diameter. In order to generate point source the laser was focused using two set of lenses. First is a concave lens with focal length of–25 mm and secondly a camera lens with focal length of 28 mm. A DG535 Digital Delay/Pulse Generator, manufacture by Stanford Research Systems, was utilized as a controller. The delay resolution is 5 ps, and the channel-to-channel jitter is typically 50 ps. The Nd:YAG laser signal was detected by BPX-65 photodiode and cascading into the delay generator. The input signal was initially delayed about 1 s prior to trigger the dye laser.

An Edmund beam splitter was used to split the dye laser beam, 30% for illumination and 70% detected by a Newport, 818-SL photodiode, P2 for optical delay measurement. The Nd:YAG laser pulses were detected by photodiode P1. All the signals are coupled to a Tektronix TDS 30520 digital phosphor oscilloscope to measure the real time delay between the two lasers. A Samsung SCB 2000 CCD video camera manufacture from KOREA is used to capture the high-speed events via a video mode with a speed of 30 frames per second. The CCD camera is interfaced to XP personnel computer with 32 bits. The camera used Matrox frame grabbers-Matrox Meteor-II family with MATLAB to directly capture live video and process the image through Matrox Inspector 9.0 software. The camera's video output port is connected to the monitor with a BNC coaxial cable. The camera is located on a 3D translational stage and set in manual mode. A zoom lens 200 mm focal length is used to magnify the event. Pre-setting is made by putting a fine knob wire in the center of the flash dye laser which coincided with the optical breakdown located in the centred of the knob region. The camera is adjusted so that a broad depth of field is achieved to get as much as possible of the action in focus. The whole view of the experimental set-up is presented in Figure 1.

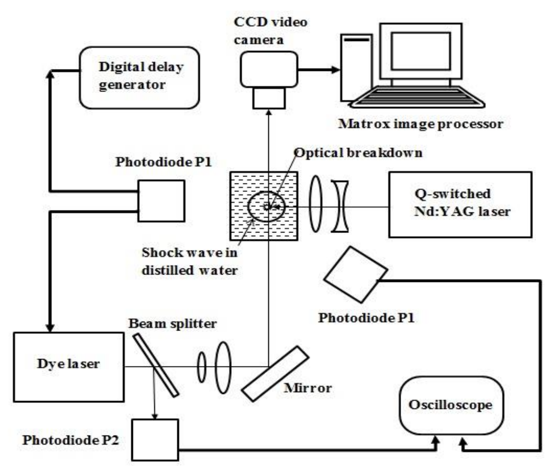


Figure 1 Experimental set-up

3.0 RESULTS AND DISCUSSION

The evolution of high speed phenomenon can be frozen with the aid of dye laser which acts as a flash. A fantastic event within the time frame can be captured because it has short pulse duration (300 ps). Some examples of the laser timing management are displayed in Figure 2. Since the source of event is double pulse, the oscillograms contain blur and contrast signal. The blurred line indicated the past signal while the contrast presents the current signal. The Nd:YAG laser was conducted in double pulses. The first pulse used to trigger the dye laser. Prior to trigger the flash light the input pulse was initially delayed about one second. Without controller, the dye laser might fire earlier than the Nd:YAG laser such as shown by the blurred line in Figure 2a. The ideal condition to grab picture of shock wave is the Nd:YAG laser signal should lead the process otherwise no event can be observed. One way to grab the desire event is by manipulating the time to trigger the dye laser (flash beam). The result for such sequential delays are displayed in Figure 2(a–c).

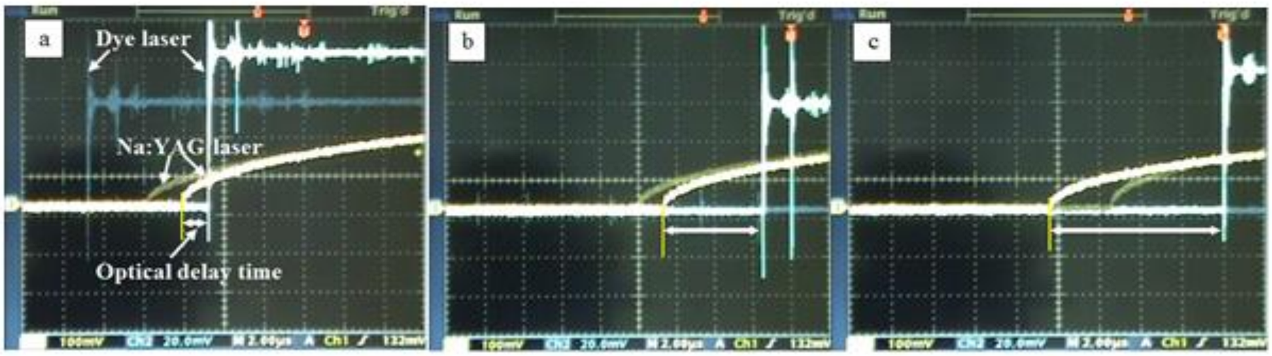


Figure 2 The optical delay time between YAG and ND laser at (a) 1.2; (b) 5.2 and (c) 8.4 μs. The YAG pulse leads the dye pulse

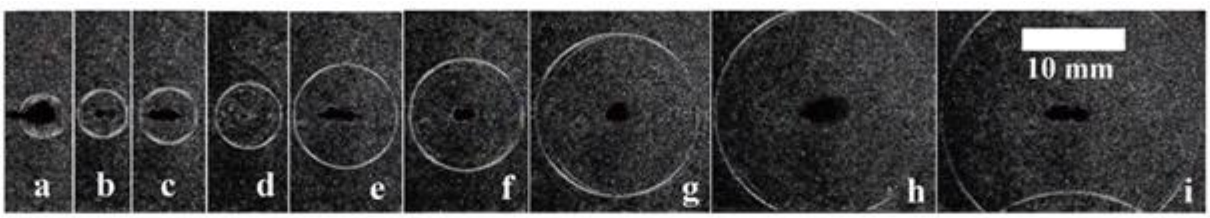


Figure 3 A sequence of a shock wave induced by laser breakdown in water, with delay time in micro second (μs) is (a) 1.2 ; (b) 1.4; (c) 1.6; (d) 2; (e) 3.2; (f) 3.6; (g)5.2; (h) 6.8 (i) 8.4

The advantage of synchronized the laser timing lead a sharp image of high speed phenomenon like shock wave to be captured. Dynamic of shock wave propagation in distilled water have been frozen by organizing this timing process such as presented in Figure 3. The longer the optical delay time allow a larger radius of shock wave to be frozen. This visualized that the shock wave have been propagated outward from the region. The shock wave radius corresponding to each delay time was measured and the results compiled in Figure 4. The average speed of sound in distilled water is obtained as 1.548 km/s. This value is in good agreement with theoretical one.

The shadowgraphs of shock wave which propagate with the speed sound in distilled water have been successfully captured. This indicates the capability of double pulse videography system to grab high speed phenomenon. It is better to note the shadowgraphy of shock wave induced by laser have been capture long time ago. However what make it different compared to this present work is the technique of capturing the event. Most high speed photography system in capturing shock wave used integrated delay circuit for synchronization. This required a lot of electronic circuits to delay each of signal involve in the system. The drawback of having such integrated delay circuit, its need scale in soldering, computer programing to command the system and require extra information like the knowledge of delay time for each of the sources involve in the system. The most critical case for synchronization desired external trigger from each units involve in the system. In contrast the present system performed with the absence of mentioned requirement. In fact the Nd:YAG laser itself does not has external trigger unit. Therefore there is no possibility to trigger it from external. One way to overcome the drawback is by introducing double pulse technique associated with delay generator.

Those lasers without external trigger are now possible to generate and capture shock wave.

Double pulse technique capable to synchronize by organizing the laser timing. The absence of integrated delay circuit will offer much simpler, easier and faster to develop a high-speed videography system. This is because less failure due to the heat dissipation or loss contact when lack of electronic circuit involve in the system. As a result, the frequency of failure to synchronize high speed photography system will be reduced or eliminated. Thus, high-speed videography with double pulse system will be an alternative method to capture shock wave and other high speed phenomena.

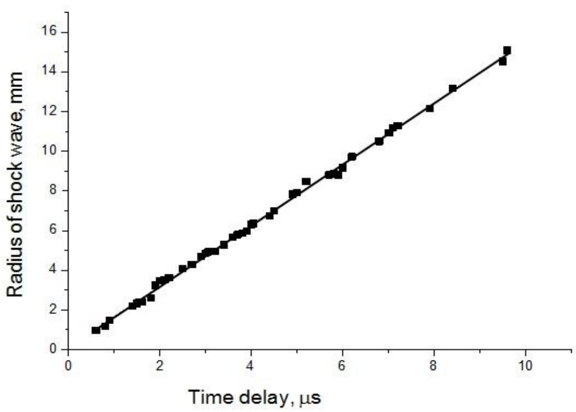


Figure 4 The profile of shock wave allow the estimation of the average sound speed in distilled water

4.0 CONCLUSION

Shock wave in distilled water can be captured via high speed videography system based on double pulses technique. The special of this current system is that it does not need integrated delay circuit. Instead it just required a delay generator to trigger the flash. Double pulses mean, one pulse used to trigger the dye for freezing the event and the other pulse to generate the shock wave. The shock wave can be captured with ease without electronic failure. Such double pulse technique is appropriated for laser without external trigger unit.

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References

[1] Dewey, John M., Kleine, Harald. 2005. High-speed Photography of Microscale Blast Wave Phenomena. 26th International Congress on High-Speed Photography and Photonics. Edited by Paisley, Dennis L., Kleinfelder, Stuart., Snyder, Donald R., Thompson, Brian J. Proceedings of the SPIE. 5580: 106-114.

[2] Noriah Bidin, Raheleh Hosseinian S, Waskito Nugroho, Faridah Mohd Marsin and Jasman Zainal. 2013. Hydrocarbon Level Detection With Nanosecond Laser Ablation. *Laser Phys*. 23: 126003

[3] Wolfrum B, Kurz T, Mettin R, and Lauterborn W. 2003. Shock Wave Induced Interaction of Microbubbles and Boundaries. *Phys. Fluids.* 15(10): 2916-2922.

[4] Margetic V, Ban T, Samek, O, Leis F. 2004. Shock-wave Velocity of a Femtosecond-Laser-Produced Plasma. *Czechoslovak Journal of Physics*. 54(4): 423-429.

[5] Inaba, K. Yamamoto, M., Shefherd, J. E., and Matsuo, A. 2007. Soot Track Formation by Shock Wave Propagation *ICCES* 4(1): 41-46.

[6] Yunfei Song, Xianxu Zheng, Guoyang Yu, Jun Zhao, Lilin Jiang, Yuqiang Liu, Bin Yang, Yanqiang Yang. 2011. The Characteristics of Laser-driven Shock Wave Investigated by Time-resolved Raman Spectroscopy. *Journal of Raman Spectroscopy.* 42(3): 345-348.

[7] Settles, G. S., Keane, B. T., Anderson, B. W. and Gatto, J. A. 2003. Shock Waves in Aviation Security and Safety. *Shock Waves* 12: 267-275.

[8] Senthilnathan Panchatsharam, Bo Tan and Krishnan Venkatakrishnan. 2009. Femtosecond Laser Induced Shockwave Formation on Ablated Silicon Surface. *J. Appl. Phys*. 105: 093103

[9] Deoksuk Jang, Jin-Goo Park and Dongsik Kim. 2011. Enhancement of Airborne Shock Wave by Laser-induced Breakdown of Liquid Column in Laser Shock Cleaning. *J. Appl. Phys*. 109: 073101

[10] Harilal, S. S., Miloshevsky, G. V., Diwakar, P. K., LaHaye, N. L. and Hassanein, A. 2012. Experimental and Computational Study of Complex Shockwave Dynamics in Laser Ablation Plumes in Argon Atmosphere. *Phys. Plasmas* 19: 083504

[11] Demaske, B. J., Zhakhovsky, V. V., Inogamov, N. A., and Oleynik, I. I. 2013. Ultrashort Shock Waves in Nickel Induced by Femtosecond Laser Pulses. *Phys. Rev. B*. 87: 054109

[12] Murray, A. K. and Dickinson, M. R. 2004. High-speed Photography of Plasma During Excimer Laser–tissue Interaction. *Phys. Med. Biol.* 49: 3325-3340,

[13] Baum, O. I., Zheltov, G. I., Omelchenko, A. I., Romanov, G. S., Romanov, O. G. and Sobol, E. N. 2013. Thermomechanical Effect of Pulse-periodic Laser Radiation on Cartilaginous and Eye Tissues. *Laser Phys.* 23: 085602

[14] Krehl, P., and Engemann, S. 1995. August Toepler—The First Who Visualized Shock Waves. *Shock Waves.* 5:1-18.

[15] Biele, J. K. 2003. Point-source Spark Shadowgraphy at the Historic Birthplace of Supersonic Transportation—A Historical Note. *Shock Waves.* 13: 167-177.

[16] Settles, G. S. 2001. *Schlieren and Shadowgraph Techniques: Visualizing Phenomena in Transparent Media*. Berlin: Springer-Verlag.

[17] Iwase, O., Süß, W., Hoffmann, D. H. H., Roth, M., Stöckl, C., Geissel, M., Seelig, W. and Bock, R. 1998. Laser-Produced Plasma Diagnostics by a Combination of Schlieren Method and Mach-Zehnder Interferometry. *Physica Scripta*. 58: 634-635.

[18] Eynas Amer, Per Gren and Mikael Sjödahl. 2008. Shock Wave Generation in Laser Ablation Studied Using Pulsed Digital Holographic Interferometry. *Journal of Physics D: Applied Physics* 41(21): 5502

[19] Hough, P., Kelly, T. J., Fallon, C., McLoughlin, C., Hayden, P., Kennedy, E. T., Mosnier, J. P., Harilal, S. S. and Costello, J. T. 2012. Enhanced Shock Wave Detection Sensitivity for Laser-Produced Plasmas in Low Pressure Ambient Gases Using Interferometry Meas. *Sci. Technol.* 23: 125204.

[20] Winter, R. E., Stirk, S. M., Ball, G. J. and Markland, L. S. 2014. Investigation of Shock-driven Dry Friction Between Stainless Steel and Aluminum Alloy. *J. Phys. D: Appl. Phys.* 47: 045501.