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A TEMPERATURE MEASUREMENT BEHIND UNDERWATER SHOCK WAVE USING LASER-INDUCED THERMAL ACOUSTICS SIGNALS

○ Ardian B. Gojani, Toshiharu Mizukaki, Kazuyoshi Takayama

Shock Wave Research Center, Institute of Fluid Science, Tohoku University, Sendai 980-8577, Japan

This paper describes a non-invasive method of temperature measurement behind underwater shock waves. This technique is based on Laser-Induced Thermal Acoustics (LITA), where in two coherent pump laser beams cross at a very narrow region in water so as to create beat signals of laser beam, which results in thermal disturbances propagating at the sound speed in water. Hence by irradiating this cross-region with a probe beam, variations of sound speed at that spot can be detected. The local temperature variation can be estimated from the value of sound speed.

1. INTRODUCTION

Unlike adiabatic compressions, shock waves in gases can enhance temperatures nearly proportional to square of shock Mach number. Hence most of hypersonic ground test facilities utilize shock waves as high temperature generators. Underwater shock waves are intensively used for various medical applications [1], because water is less compressible than gases and hence higher pressures are readily created without enhancing temperatures.

In medical applications it is still an open question that by focusing of underwater shock waves how high temperatures can be. The high temperatures generated by underwater shock focusing, even momentarily at localized spot may damage human tissue. So far we surveyed open literatures, there is no reliable temperature measurement behind underwater shock waves particularly overpressures of which are less than 100 MPa. This is the range of pressures under study for medical applications. It is estimated that within this pressure range the shock overpressure should be in between room temperature to highest not more than boiling temperature. Insertion of solid thermometers or temperature sensitive gauges into water is extremely inaccurate due to their heat capacity solid gauges will never detect temperature variations for a few microsecond or even less.

The equations of state of water so far reported are constructed not to estimate such subtle temperature enhancements but in many cases to predict analytically higher temperatures in water which may be generated by the deposition of very high energies [2].

This paper describes a non-invasive temperature measurement technique based on four beam mixing in water.

2. GENERATION OF UNDERWATER SHOCK WAVES

The generation of underwater shock waves, particularly plane ones, is not easy as optimistic people may consider. Spherical shock waves, on the contrary, are relatively easy to produce using electrical discharge or explosion of micro-explosives. In the Shock Wave Research Center (SWRC) we have been using 10 mg silver azide pellets detonation in a water chamber for generation of shock waves. The pellets are pasted on the tip of thin optical fiber and irradiation of Q-switched Nd:YAG laser beam (7ns pulse width and 25 mJ/pulse) ignites the pellets. Nearly perfectly spherically shaped underwater shock wave could be generated using this method [3]. From interference fringe distributions its characteristics can be quantitatively determined. Although its Mach number is very close to unity, it still maintains non-linear characteristics of shock waves.

3. TEMPERATURE MEASUREMENT BEHIND SHOCK WAVE

Laser-induced thermal acoustics (LITA) is a four-wave mixing technique that can be used for obtaining, among other properties, the speed of sound of medium simulated by laser beam input [4]. This method is non-invasive, fast enough to observe short duration phenomena, and with high temporal and spatial resolutions.

Physical principle for obtaining LITA signal lays in the following: two pulsed laser beams (pump beams, driver beams) of equal strength, that is equal wavelength λ_d, intersect at a shallow angle θ in test section, as shown in Fig. 1. In the intersection region these beams interfere, thus creating an electric field grating by molecular mechanisms of thermalization and electrostriction, which results in a density and hence in a refractive index grating. The spatial period of the grating will be $\Lambda=\lambda/2\ \sin(\theta/2)$. The evolution of this grating can be examined by a continuous interrogation beam (source beam, probe beam) which is directed at the phase matching angle (θ_{ph}) at the grating. Phase matching is equivalent to the focusing the probe laser beam at its Bragg angle, given by $\theta_{ph}=\arcsin(\lambda_{probe}/2\Lambda)$.

So, part of the probe beam that passes through density grating is coherently scattered into a signal beam, the so-called LITA signal. Since the density grating evolves over time and the LITA signal intensity is proportional to the instantaneous density grating modulation depth, the LITA signal allows us to observe the grating evolution. The speed of sound is encoded in the LITA signal as the Brillouin frequency, i.e. the speed of sound divided by the fringe spacing of the density grating. The following diagram shows the pattern of analyzing the results gained from LITA signal:

LITA signal: Experimental condition: $\Lambda=\lambda/2\sin(\theta/2)$
FFT analysis: LITA signal frequency : $\tau_{acoustics}=1/f_{LITA\ siignal}$ Speed of sound $C_{sound}=\Lambda/\tau_{acoustics}$
Temperature-speed of sound relation   Water temperature $T_{water}=F(C_{sound})$

4. EXPERIMENTAL SET UP

Previous experiments for measuring water temperature by LITA have shown progress in obtaining the signal, but the precision of the measurement was not within the desired limit. Therefore, with the aim of increasing the accuracy of the measurement, some improvements were introduced for the experimental setup.

Fig. 2 is a schematic diagram of the experimental arrangement. The scattering field will be generated by dubling Nd:YAG laser beam, operating at 532 nm with a pulse width of 100 picosecond, while the probing beam will be used from a CW Verdi laser with 0.1-2 W power at 532 nm wavelength.

In order to avoid laser florescence and to keep population inversion in dye large, an acoustic optical modulator will be used. Pellin Broca prism will be used to prevent unwanted stimulated lights getting into detector.

The detection system consists of high speed photo multiplier tube (PMT) and a 2.5 GHz, 20 GS/s 4 channel DPO digital oscilloscope as data recorder.

Initially the experiment will be performed in still water with the aim to obtain the LITA signal. Later it will be investigated the possibility of usage of LITA technique for moving water by the influence of shock wave.

5. CONCLUSION

Preliminary experimental results suggest that LITA can be utilized to measure unsteady temperature field caused by shock waves in water. LITA signal frequency can be improved by employing picosecond laser and using acousto-optics modulators for controlling the intensity and position of laser beam.

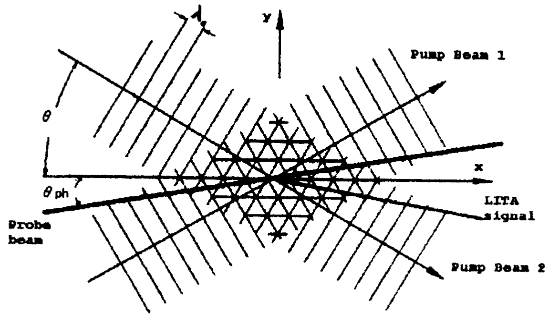

Fig.1.Obtaining LITA signal from the scattering of probe beam from the fringes of pump beams.

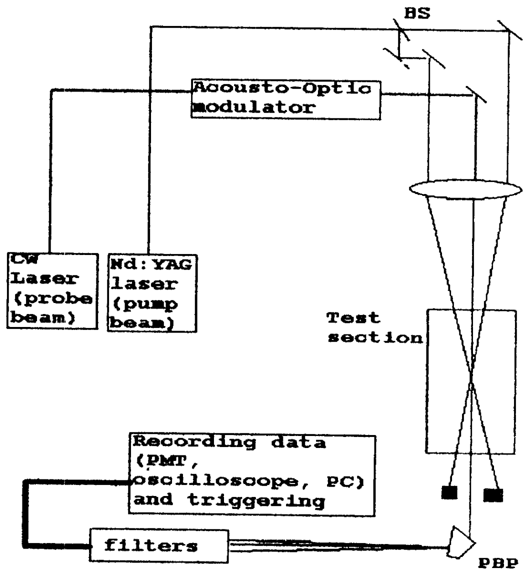

Fig. 2. Optical set up for LITA experiment

REFERENCES

1) K. Takayama, Proc. 22nd Int. Symp. Shock Waves, London, 2000, p. 24-31

2) H. Cole, *Underwater Explosions*, Dover, 1948

3) N. Nagayasu, PhD Thesis, Tohoku University, 2000

4) E. B. Cummings, I. A. Leyva, and H. G. Hornung, Appl. Opt., v. 34, 1995, p. 3290-3302

5) T. Mizukaki, P. M. Danehy, G. C. Herring, and K. Takayama, Proc. of Shock Wave Symposium in Tsukuba, 2002, p.21-24..