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# Shock Wave Emission during Cavitation Bubble Collapse in Free Liquid

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**ABSTRAK**

Kajian dibuat terhadap perambatan gelombang kejutan yang dijana ketika penguncupan gelembong kaviti. Penguncupan didapati berlaku sebanyak empat atau lima kali dalam satu osilasi gelembong kaviti. Gelembong kaviti sekunder menjelma dalam proses pengembangan kedua. Bila kaviti berpecah dua, gelombang kejutan berganda merambat pada sumber titik yang berlainan pada penguncupan yang berikutnya. Gangguan yang di sertai perambatan gelombang kejutan berganda wujud akibat dari keruntuhan laser yang berganda.

**ABSTRACT**

Shock wave emission due to cavitation bubble collapse was studied. Four or five time collapses occurred in a single oscillation of a cavitation bubble. The secondary cavitation bubble appeared in the rebound process. When the cavity was split during the first collapse, double shock waves were radiated with separate centres in the following collapse. A gross distortion and multiple shock waves were radiated due to multiple breakdown.

**Keywords: cavitation bubble, collapse, shock wave, laser, breakdown, split, rebound, multiple, distortion, microjet**

## INTRODUCTION

Experimental cavitation bubble dynamics have advanced since the invention of the laser. The intense light pulse of a laser can be focused into a liquid to form cavities. Cavitation is a dynamic phenomenon, as it is concerned with the growth and collapse of cavities. Cavitation damage is predominantly caused by impulse pressure produced during cavity collapse.

Experiments on the collapse of bubbles have been performed by numerous investigators (Naude and Ellis 1961; Benjamin and Ellis 1966; Kling and Hammitt 1972; Lauterborn and Bolle 1975). Jones and Edwards (1960) observed that a shock wave radiated into the liquid at the instant of the collapse of spark-induced bubbles. Kuttruff (1962) observed not only shock waves, but also flashes of sonoluminescent light from the ultrasonic cavitation. Ebeling and Lauterborn (1977) observed, by cinematic holography, shock waves emanating from collapsing bubbles generated by laser pulse.

Tomita and Shima (1986) suggested that cavitation erosion is attributed to the action of shock waves emitted during bubble collapse.

Blake *et al.* (1986), using numerical studies, succeeded in calculating pathlines and pressure contours in the neighbourhood of collapsing bubble. Vogel and Lauterborn (1988) measured the pressure amplitude, the profile and the energy of shock waves emitted during spherical bubble collapse by using hydrophone and optical detection technique. In this paper, shock wave propagation during collapse was studied using shadowgraph method and high speed photography techniques. A model single cavitation bubble was generated by focused laser and recorded by SLR camera.

## MATERIALS AND METHODS

Breakdown and cavity formation were achieved with a giant pulse from a Nd:YAG laser (8 ns duration, 180 mJ energy per pulse) which was focused into the liquid under study with a concave lenses of focus length = -25 mm and converging lens of 28 mm focus length. A nitrogen-pumped dye laser emitting at wavelength of 514 nm and a pulse width of 300 ps, acted as a flash for the camera. The beam was expanded and collimated to cover the cavity region. The two lasers were synchronized by using a trigger unit. A beam-splitter was placed in the path of the dye laser and reflected the beam on to a large area photodiode. The optical delay measured from the instant of breakdown was displayed on the Tektronix TDS 540 oscilloscope (bandwidth of 500 MHz). The collapse zone was recorded by using a Pentax SLR K1000 camera. Experimental details are shown in *Fig. 1*.

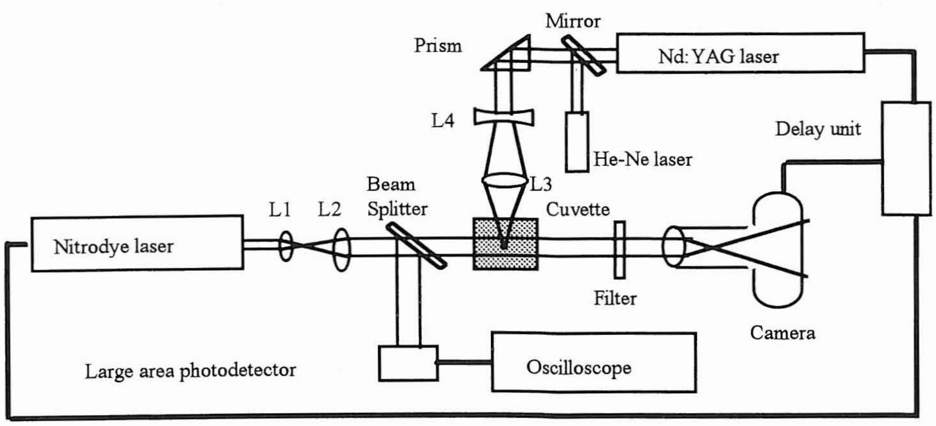


*Fig. 1 Experimental arrangement*

## RESULTS AND DISCUSSION

Cavitation bubble dynamics are produced as a result of a microexplosion in the focused zone. The dynamics of the cavitation bubble refer to the expansion, contraction, collapse and re-expansion process. During the collapse of cavitation, a second shock wave is emitted in the space. This shock wave is similar to the one observed in laser breakdown.

The pictures taken immediately after a series of cavitation bubble collapses are illustrated in *Plate 1.* In each picture the shock wave emitted during bubble rebound can be seen as a dark ring surrounding the cavity. The first collapse occurred at a delay of 184 µs. The shock waves were weak and only faintly visible. This may be because they extend far out of the focal plane of the photographic system. *Plate 1b* shows double shock waves emitted during collapse. Analogous to Doppler effect, the microjet acted as a source of sound moving downward. The shockfronts are nearer to the moving direction of motion, and quite a distance from the opposite direction. The same phenomenon is seen in *Plate 1c.*

Several microbubbles were generated both during rebound process and cavity collapse. This can be seen on top of the microjet (see arrow in *Plate 1b*). These microbubbles are also known as secondary cavitation bubble by Gibson (1968). *Plates 1d, 1e,* show the cavity split immediately after collapse. Thus, double shock waves were emitted separately in the next collapse, as shown in *Plate 1f.*

When there is not only one single point of breakdown in the liquid but several nearby, a single big cavity may nevertheless result upon growth of each created bubble. Such cavities usually collapse with large distortion and radiate a multiplicity of shock waves as shown in *Plates 1g, 1h.*

In the lifetime of each cavitation bubble, four or five collapses occur. This is clearly seen when pictures were taken at different delay times (see *Plate 1*). The oscillations of the bubble are damped by the emission of a spherical shock wave during each bubble collapse and the dissipation of heat into the liquid. A pressure pulse of high intensity spreading out from each collapse cavity is an important, and usually an undesirable feature of cavitation. It is heard as a disturbingly loud noise in the cuvette. The continual collapse of cavities leads rapidly to deterioration and erosion of nearby solid surfaces.

## CONCLUSION

Cavitation bubble collapse induced by laser generates shock waves of different shapes depending on the numbers of optical breakdowns. One single breakdown produces a spherical shock wave, whereas a multiple breakdown gives rise to large distortion and multiple shock waves during cavity collapse. Secondary cavitation bubbles appear in the rebound process. Split cavitation bubbles produce multiple shock waves at different centres in the intermediate cavity collapse.

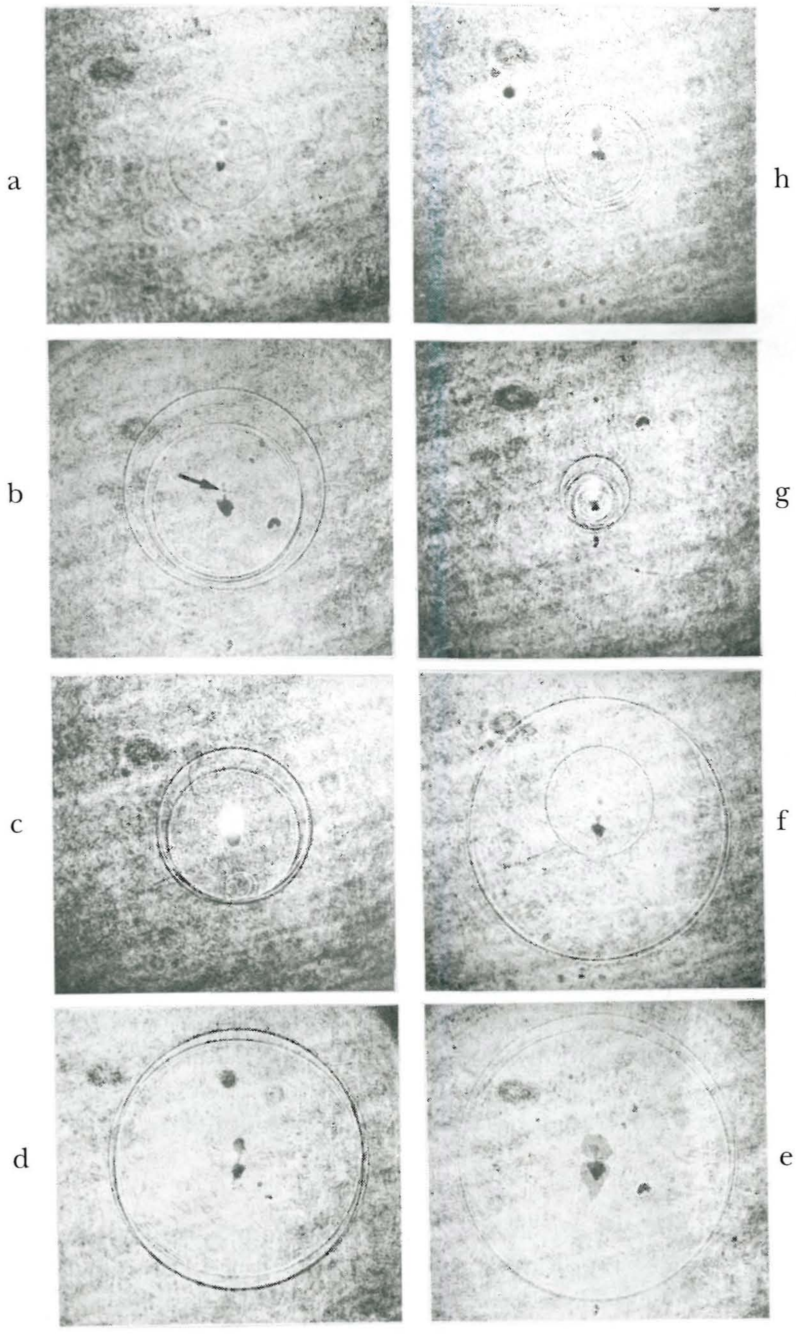


*Plate 1: Shock wave emission during cavity collapse. Respective delay of the picture: a. 184, b. 217, c. 231, d.232, e. 222, f. 356, g. 231, h. 345 µs. Magnification, 5X*

## ACKNOWLEDGEMENTS

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