CHARACTERISTICS OF LASER ULTRASONIC BY MULTI-BEAM IRRADIATION

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Abstract

Multi-beam irradiation technique was introduced to see the amplitude variation of laser ultrasonic at the ablation regime. Matlab was used to simulate how the ultrasonic intensity varied with spot size, inter-beam distance and number of irradiation spots. Cross configuration with 5 beams was chosen to the best concept of multi-beam irradiation technique by considering optimum arrangement of laser optic components, systematic control of the module and simple-compact design. Ultrasonic amplitude with laser energy approaches saturation near 1, 000mJ by single beam irradiation of 1,350mJ pulsed laser to a spot of 3mm diameter. Dominant attribution to the laser ultrasonic comes from low frequency components. The 5 beams of each 270mJ were also irradiated on the separate 5 spots by changing inter-beam distance. The ultrasonic intensity could be increased to an additional 10 to 40% with the change of an inter-beam distance.

Introduction

The concept of multiple pulses technique is introduced to avoid saturation phenomenon of laser ultrasonic at the high power irradiation of pulsed laser [1]. The saturation means that there is no further increase of ultrasonic amplitude with the increase of incident laser power at the ablation regime of laser ultrasonic [2]. The multi-beam technique is also useful to irradiate high energy pulsed laser which can be delivered through a bundle of optical fibers where each optical fiber has delivery limit of laser energy around 250mJ up to now. The simulation was firstly performed to see how the ultrasonic intensity varied with spot size, inter-beam distance and number of irradiation spots. Cross configuration with 5 beams as in figure 1 was chosen to the best concept of multiple pulses technique by considering optimum arrangement of laser optic components, systematic control of the module and simple-compact design.

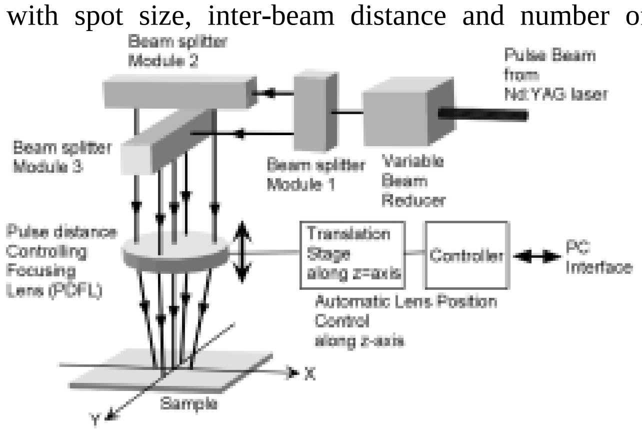

Figure 1 : Conceptual Design of multi-beam irradiation module

Experimental Procedure

A generation laser of Nd:YAG pulsed laser (max. 1600mJ/pulse) was focused to circular spots of 3mm diameter on a plain carbon steel specimen that had a thickness of 10mm. A 4MHz longitudinal contact transducer and a confocal Fairy-Perot interferometer were used to measure ultrasonic amplitude respectively. A continuous Nd:YAG laser of 400mW was focused to the opposite side of the specimen with a spot of 3mm diameter for the interferometer as in figure 2.

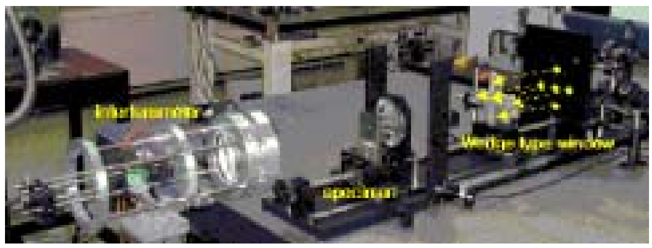

Figure 2 : Experimental arrangement from beam split unit (multi-beam irradiation module) to interferometer

Wedge-type windows for a constant spot size and convex-concave quartz lenses for a stepwise beam diameter were installed at the multi-beam irradiation apparatus to control an inter-beam distance and a spot size independently. The wedge-type windows maintain spot size constant even though the distance between specimen and focusing lens varies because the wedge-type windows only deflect the beam direction to the specimen without changing beam diameter as the distance varies between specimen and the wedge-type windows.

Quartz lenses were used to deliver high energy of laser safely to the target. The combined set of convex and concave quartz lenses was designed and installed so that we could get our intended spot diameter by an appropriate combination of lenses. At this trial 3mm spot diameter was achieved by simultaneous use of large diameter focusing lens with the quartz lens set. Figure 3 shows experimental arrangement from generation laser to the beam split module and the convex and concave quartz lens set to get beam size control as in a blue circle. The detail arrangement from split module to the interferometer was already shown in figure 2.

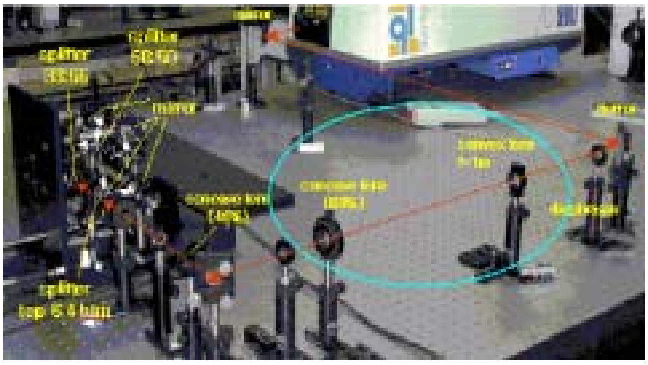

Figure 3 : An experimental arrangement from laser source to beam split unit and combined quartz lens set of convex and concave for beam size control (in a blue circle)

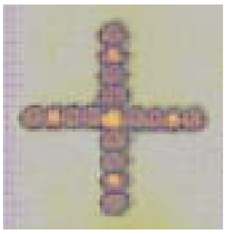

Figure 4 : Irradiated 5 cross beams with inter-beam distance of 0, 5, 10, 15 and 20mm at the spot diameter of 3.0mm

The irradiated spot patterns of 5 cross configuration are shown at figure 4. The spot diameter of 3.0mm is constant throughout inter-beam distance of 0 to 20mm as in figure 4. This shows that wedge-type windows for constant spot size and convex-concave quartz lenses for stepwise beam diameter control work successfully for our multiple laser beam irradiation purpose.

Results and Discussion

1 beam irradiation with laser energy

Ultrasonic amplitude was measured according to generation laser energy. One whole beam of 1,350mJ pulsed laser was focused to a 3mm spot of the specimen and changed laser energy like in figures 5 and 6. A longitudinal contact ultrasonic transducer of Krautkramer (K4N, diameter 10mm) model was used in figure 5 while a confocal Fairy-Perot interferometer was used in figure 6 where continuous wave of Nd:YAG laser of 400mW power was focused to a spot of 3mm on the opposite side of irradiated specimen. The ultrasonic amplitude with pulsed laser energy goes to saturation over 1,050mJ and the echo signal looks like symmetric between upper and lower peaks in figure 5. In figure 6 the amplitude approaches saturation near 1,000mJ of pulsed energy.

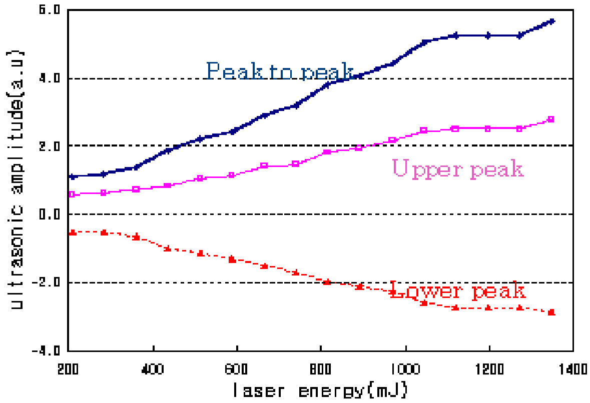

Figure 5 : Ultrasonic amplitude with pulsed laser energy measured by a contact transducer

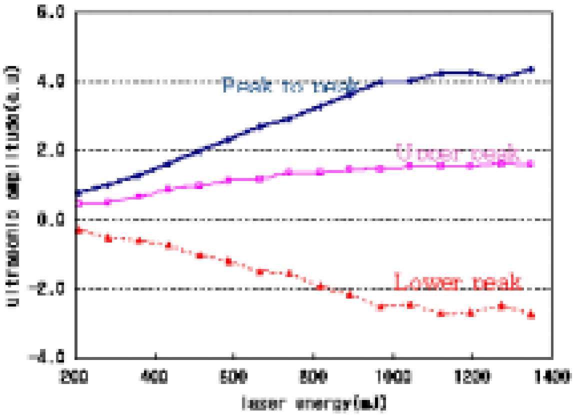

Figure 6 : Ultrasonic amplitude measured by a Fabry-Perot interferometer

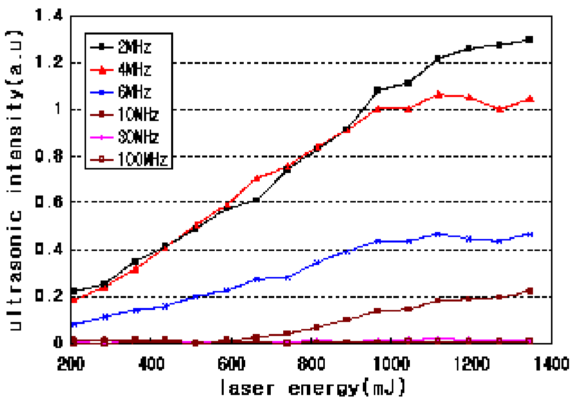

Figure 7 : Frequency dependence of ultrasonic amplitude from a Fabry-Perot interometer

The ultrasonic intensity with frequency was calculated through the process of fast Fourier transformation from a peak of time domain signals and was plotted as in figure 7. The figure shows that the ultrasonic amplitude dominantly comes from low frequency components.

Simultaneous 5 multi-beam irradiation to a spot

All the 5 laser beams were irradiated to make one spot on the target specimen where maximum value of each pulsed beam has about 270mJ and spot size of 3mm diameter. Figure 8 shows the ultrasonic amplitude with laser energy and figure 9 does the frequency dependence of ultrasonic amplitude measured by a Fabry-Perot interferometer. The ultrasonic amplitude goes to saturation near 800mJ of laser energy as in figure 8. The dominant frequencies to the laser ultrasonic seem to be low frequency components of below 6MHz as in figure 9.

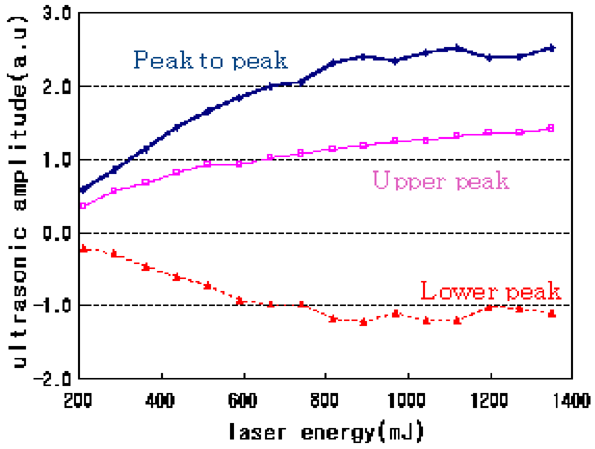

Figure 8 : Ultrasonic amplitude generated by 5 multi-beams on a spot of 3mm diameter and measured by a Fabry-Perot interferometer

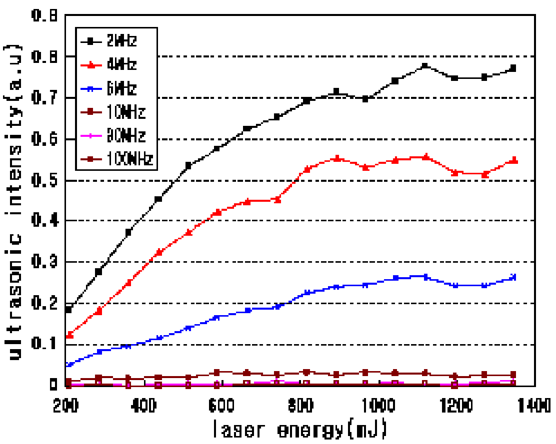

Figure 9 : Frequency dependence of ultrasonic amplitude by 5 multi-beam irradiation

5 multi-beam irradiation with inter-beam distance

Ultrasonic amplitude at spot size of 3mm was measured along with inter-beam distance as shown in figure 10. The inter-beam distance was defined to the distance between the center of a center spot and one center of adjacent 4 spots at the cross configuration of 5 multi-beam irradiation module. The total laser energy of 5 beams was 1,350mJ so that each beam has about 270mJ of pulsed laser energy. The ultrasonic amplitude changes with the inter-beam distance and reaches maximum value when inter-beam distance is between 1.0 to 3.0mm. For the case of figure 10, it is seen that an additional 40% of ultrasonic amplitude can be increased by varying an inter-beam distance for multi-beam irradiation scheme.

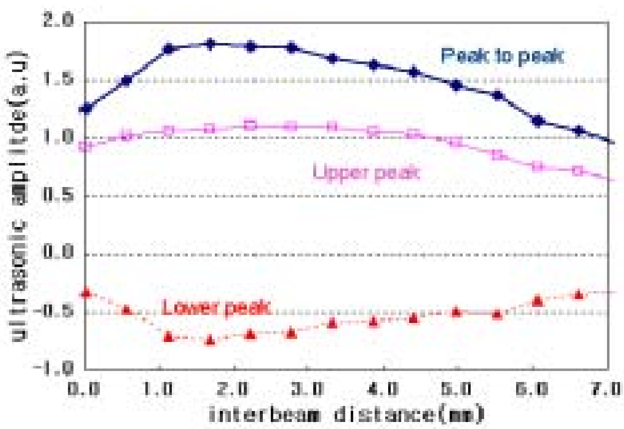

Figure 10 : Ultrasonic amplitude with inter-beam distance by 5 multi-beam irradiation

Conclusion

Multi-beam irradiation technique was introduced and cross configuration with 5 beams was chosen for the purpose. Wedge-type windows were installed for constant spot size and convex-concave quartz lenses for stepwise beam diameter control. The new designed experimental arrangement works successfully for our multi-beam irradiation purpose. Dominant attribution to the laser ultrasonic was found to come from low frequency components. The 5 beams of each 270mJ were irradiated on the separate 5 spots by changing inter-beam distance and the ultrasonic intensity could be increased by an additional 10 to 40% with the change of an inter-beam distance.

References

[1] R.J. Dewhurst, D.A. Hutchins, S.B. Palmer and C.B. Scruby, J. Appl. Phys., Vol. 53, pp.4064, 1982.
[2] C.B. Scruby and L.E. Drain, Laser Ultrasonics – Techniques and Applications, Adam Hilger, Bristol, 1990.