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THE LASER-GENERATION OF SURFACE ELASTIC WAVES AT FREE METAL SURFACES

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ABSTRACT
It has been demonstrated that the interaction of Q-switched, Nd:YAG laser pulses with free metal surfaces generates both Rayleigh- and fast-surface waves. Using conventional ultrasonic probes made from PZT ceramic, surface waves were detected at laser energies below the threshold for visible damage of targets. A technique is presented for generating directional beams of ultrasonic Rayleigh wave pulses.

INTRODUCTION

Recent investigations (1,2) have demonstrated that Rayleigh waves may be generated when Q-switched laser pulses interact with the surface of solid targets. However, either laser pulses that damage the targets were used (1) or thin layers were applied to the target surfaces (2). In contrast, we wish to report that both Rayleigh and fast surface waves can be laser-generated at free metal surfaces without incurring any visible damage of the targets. In anticipation of applications in non-destructive testing, we have also developed a technique for the contactless generation of comparatively powerful, directional beams of ultrasonic Rayleigh wave pulses.

EXPERIMENT

The Nd:YAG laser used in this investigation, delivered up to 50mJ in a multimode Q-switched pulse of 40ns half-width duration. Surface waves were detected with two different probes both made from PZT ceramic. One probe (a commercially made wedge type) was heavily damped and sensitive to a range of frequencies from 1M to 5MHz. The other probe (a slab of longitudinally polarised PZT held at 45^{o} to target edges) was highly resonant and operated over a very limited frequency range centred at 3MHz.

Laser-generated Rayleigh wave pulses were detected on aluminium, brass and steel targets. On aluminium surfaces, for instance, an unfocused 1mJ laser pulse produced signals of up to 3mV peak-to-peak from the wedge probe placed 5cm from the irradiated area. This corresponded to a laser energy density of 6×10^{5}Wcm^{-2} which is to be compared with an experimentally derived value of 2×10^{7}Wcm^{-2} for the threshold of laser-induced target damage. Use of the wedge probe revealed that the Rayleigh pulses were dipolar in nature as illustrated in Figure 1. The upper trace was obtained by inserting a circular stop into the laser beam allowing only the central 0.8mm diameter portion through; the lower trace was obtained with a 2.0mm diameter stop. A comparison of the two traces indicates the duration of the pulses is similar to the time a Rayleigh wave would take to traverse the irradiated area. The source of Rayleigh waves can, therefore, be associated with the edges of the irradiated area but not the centre.

Fast surface waves have been generated previously with conventional techniques (3). We now report such generation using laser pulses. Fast surface wave

THE LASER-GENERATION OF SURFACE ELASTIC WAVES AT FREE METAL SURFACES

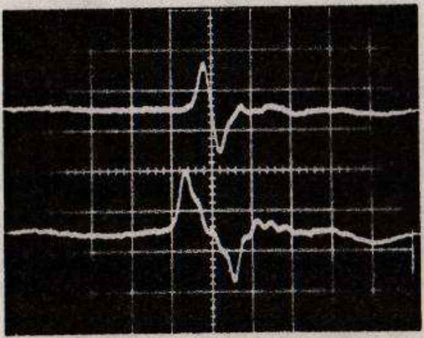

FIGURE 1: RAYLEIGH WAVE PULSES ON ALUMINIUM TARGET, BROADENING WITH DIAMETER OF LASER BEAM (SEE TEXT). TIME SCALE: 0.5μs A DIVISION.

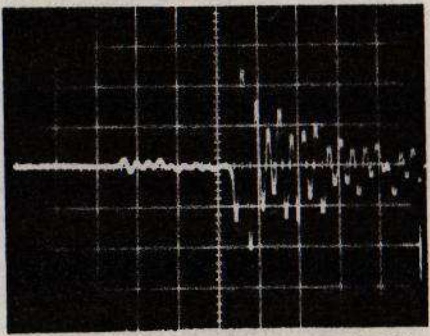

FIGURE 2: FAST SURFACE WAVE PULSE (LEFT) ARRIVING BEFORE THE STRONGER RAYLEIGH PULSE (RIGHT). GENERATED BY 20mJ LASER PULSE ON ALUMINIUM TARGET. TIME SCALE: 0.5μs A DIVISION.

pulses were detected with the edge probe (see Figure 2) and arrived before the slower but stronger Rayleigh wave pulses (fast surface waves propagate at the longitudinal bulk wave velocity (3), having no shear components). As the distance between the irradiated area and probe was increased, the fast waves arrived proportionately later, thus confirming the signals were acoustic in origin. The velocity of the fast waves on aluminium surfaces was estimated as $6100 \pm 300 ms^{-1}$, compared with an accepted value (4) of $6374 ms^{-1}$ for longitudinal bulk waves.

Line sources of Rayleigh wave pulses have been generated by focusing laser pulses onto free metal surfaces with a cylindrical lens. This resulted in the preferential propagation of the high-frequency components of the Rayleigh wave pulses in directions normal to the line. More precisely, the directional characteristics of individual frequency components of the Rayleigh wave pulse were well described by the following expression (adapted from the theory of emission of continuous, single frequency acoustic waves propagating from a line source into an infinite, homogeneous medium (5)):

$$R_\alpha = \frac{\sin\left(\left(\frac{\pi \ell n}{c}\right)\sin\alpha\right)}{\left(\frac{\pi \ell n}{c}\right)\sin\alpha}$$

where R_α = ratio of the amplitude of a frequency component for an angle α to that for an angle $\alpha = 0$; the direction $\alpha = 0$ being normal to the line.

c = velocity of Rayleigh waves on the target material.

ℓ = length of line source.

n = frequency of component.

Values of R_α were determined experimentally for those frequency components falling into the narrow range of the edge probe. The laser pulses were focused at the centre of an end face of a cylindrical sample, as illustrated in Figure 3; the end face (with edge probe fixed to it) was then rotated about its centre with the normal to the surface defining the optic axis of the laser system. A typical directivity pattern is depicted in Figure 4. In the direction of maximum propagation, signals of up to 150mV peak-to-peak were produced from the edge probe at laser energies below the damage threshold. In fact, the amplitude of the beams was sufficiently large to produce a long train of signals from the edge probe, corresponding to multiple reflections from diametrically opposite points on the edges of the irradiated surface as shown in Figure 5.

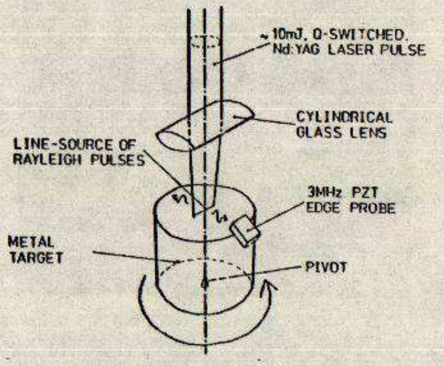

FIGURE 3: APPARATUS FOR DETERMINATION OF DIRECTIVITY PATTERNS OF LINE-SOURCES OF RAYLEIGH PULES GENERATED BY LASER-IRRADIATION.

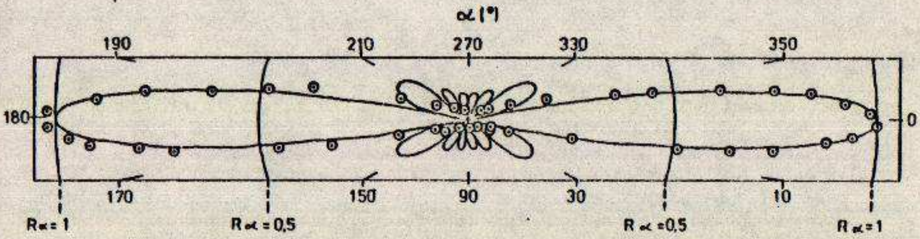

FIGURE 4: DIRECTIVITY PATTERN FOR LINE-SOURCE OF RAYLEIGH PULSES, LASER-GENERATED AT FREE ALUMINIUM SURFACE. THEORETICAL CURVE NORMALISED TO EXPERIMENTAL POINT AT $\alpha = 0°$ ($L = 4.5$mm., $C = 2906 ms^{-1}$, $n = 3$MHz)

Also in agreement with the above expression, experiments showed that the directional width of the Rayleigh beams broadened as the length of the line source was shortened. Further, line sources of a given length produced narrower beams on brass targets than those of aluminium or mild steel as the wave velocity in brass is slower. The directional characteristics were found to be independent of laser energy below the damage threshold.

It is anticipated that this technique will be of use in the remote non-destructive location of surface flaws.

THE LASER-GENERATION OF SURFACE ELASTIC WAVES AT FREE METAL SURFACES

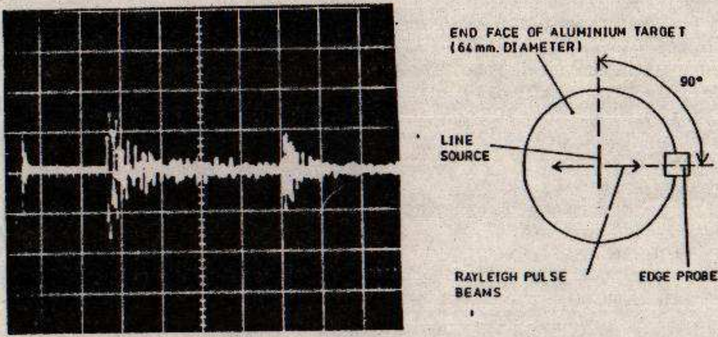

FIGURE 5: LEFT: FIRST TWO OF A TRAIN OF PULSES RESULTING FROM THE MULTIPLE-REFLECTIONS OF RAYLEIGH BEAMS. THE FIRST PULSE CORRESPONDS TO THE BEAM DEPICTED ON THE RIGHT, DIRECTLY ARRIVING AT THE PROBE; THE SECOND TO THE OTHER BEAM AFTER REFLECTION FROM OPPOSITE EDGE.(TIME SCALE: 5μs A DIVISION; VERTICAL SCALE: 1mV A DIVISION. LASER ENERGY: ~ 1mJ.)

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