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X. Jia, D. Royer, G. Quentin. PULSED LASER EXCITATION AND OPTICAL DETECTION OF RAYLEIGH WAVES ON A METALLIC SPHERE. Journal de Physique IV Proceedings, 1992, 02 (C1), pp.C1-789-C1-792. 10.1051/jp4:19921172 . jpa-00251133

HAL Id: jpa-00251133

<https://hal.science/jpa-00251133>

Submitted on 4 Feb 2008

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PULSED LASER EXCITATION AND OPTICAL DETECTION OF RAYLEIGH WAVES ON A METALLIC SPHERE

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Résumé. Nous avons engendré et détecté optiquement des ondes de Rayleigh sur une sphère métallique. La source est un laser YAG fonctionnant en régime pulsé. Le déplacement mécanique est mesuré, au point diamétralement opposé au point d'impact, par une sonde interférométrique hétérodyne. Les fréquences de résonance d'une sphère en acier inoxydable de diamètre 20 mm ont été déduites directement du spectre du signal ainsi que les variations de la vitesse de groupe. Les résultats expérimentaux sont en bon accord avec les valeurs prévues par l'analyse.

Abstract. Rayleigh waves have been optically generated and detected on a metallic sphere. The source was a pulsed YAG laser. The mechanical displacement was measured, at a point diametrically opposite to the laser impact, by an heterodyne interferometer. The resonance frequencies of stainless-steel sphere of diameter 20 mm was rapidly obtained from the fast Fourier transform of the probed signal. The variation of the group velocity was also deduced from the resonance spectrum. Experimental results agree with the analysis.

1. INTRODUCTION

Surface acoustic waves travelling along curved surfaces have been an interesting subject in geophysics and acoustics since a long time [1,2,3]. In acoustic scattering field, targets like cylinders or spheres are usually excited by acoustic waves incident from the ambient liquid. The resonances are physically explained in terms of surface acoustic waves which, at an eigenfrequency, match phases during repeated circumnavigation around the target. The constructive interferences, establish the resonance of the target.

We describe here an experimental approach to study surface acoustic waves on axisymmetrical objects with pulsed laser excitation. The use of transient generation permits not only identification of different types of circumferential waves via their arrival times but also broadband frequency analysis. The elastic waves are investigated without any mechanical contact with the aid of an optical interferometric probe [4]. In a previous work [5] this noncontact method has been used to study the propagation of Lamb waves in plates and cylindrical shells as well as surface waves in cylinders and spheres.

In this paper we discuss only the generalized Rayleigh acoustic waves on free metallic spheres. The use of a fast Fourier transform of the optically probed circumferential signals allows us to establish the resonance spectrum of Rayleigh waves on spheres. The group velocity of Rayleigh waves is also deduced.

2. EXPERIMENTAL SET-UP

The experimental set up is shown in Fig.1. The YAG laser ($\lambda=1.06 \mu\text{m}$) providing optical pulses of energy 100 mJ and of a duration 10 ns is focused into a spot of a diameter about 2 mm on a stainless

steel sphere. The resulting power density of 100 MW/cm^2 produces a slight material evaporation (ablation regime) which creates consequently a stress normal to the surface. The propagation of the launched elastic waves is investigated by means of an optical heterodyne interferometer. This probe, associated with a broadband electronic detection, measures the normal mechanical displacement with a sensitivity of 0.5 \AA for a 30 MHz detection bandwidth [4]. The probed signals are sampled and averaged by a digital oscilloscope and then sent to a micro-computer.

3. RESULTS AND DISCUSSION

Fig. 2 shows the transient mechanical displacement, detected on a stainless steel sphere of diameter 20 mm by the optical probe at the pole diametrically opposite to the laser impact (Fig. 1). The echoes correspond to the propagation of surface waves around the sphere, diverging from one pole and converging towards the other and so on [5,6]. The dominant generation of surface waves of Rayleigh type is explained by the fact that the photoacoustic source is located close to the material surface and consequently most of the photothermal energy is converted into surface acoustic waves instead of bulk waves [7]. As clearly seen in the time signals (Fig. 2), the Rayleigh waves on a sphere exhibit a dispersive effect: the longer the propagation path, the wider the pulses. This effect, which does not appear for Rayleigh waves travelling on a plane, is due to the curvature of the surface [6] and has been also observed on cylinders [5,8].

Fig. 3 displays a fast Fourier transform of the whole signal in Fig. 2. The envelope of the resonance spectrum (bottom curve) is similar to the spectrum of the first echo (top curve). The positions of the maxima in the frequency spectrum correspond to the different orders n of resonance of the Rayleigh waves on the sphere. The longitudinal and shear wave velocities in the sphere have been measured as 5.99 km/s and 3.29 km/s . Table I gives the 20 first resonance frequencies measured from this spectrum as well as the calculated values [9]. The absence of the mode $n = 0$ is explained by the fact that this mode corresponds to a radial vibration and not to a circumferential surface wave. The discrepancy of about 1% observed between theoretical and experimental results arises probably from the frequency resolution of the discrete FFT limited by the 10 kHz sampling frequency of the signal. The results demonstrate that, for resonance studies of surface acoustic waves, the present method is much faster than the swept frequency measurement [9].

If n and $n+1$ are two successive resonance modes, then the condition of constructive interference requires:

$$\Delta k = k_{n+1} - k_n = \frac{(n+1)}{a} - \frac{n}{a} = \frac{1}{a} \quad (1)$$

where k_n is the wave number of n th modal resonance and a the radius of the sphere. Assuming that f_n is the n th resonance frequency, we deduce from (1) the following formula [9]:

$$\frac{\Delta \omega}{\Delta k} = \frac{2 \pi (f_{n+1} - f_n)}{\Delta k} = 2 \pi a \Delta f \xrightarrow{\Delta k \rightarrow 0} V_g \quad (2)$$

which gives approximately the group velocity only from the frequency difference Δf [9]. The experimental values V_g , deduced from this method, are plotted versus the product of shear wavenumber by sphere radius ($k_n a$) in Fig. 4. The decrease of the group velocity with frequency is slight. However it confirms the observation of the low frequency components arriving first (Fig. 2). The discrepancy from the calculated dispersion curve comes from the imprecision in the measurement of the resonance frequencies.

4. CONCLUSION

Rayleigh waves on metallic spheres have been generated by a pulsed laser and detected by an optical interferometer. The Fourier transform of the probed signal allows us to build up rapidly the resonance spectrum over a broad frequency range. The group velocity of the Rayleigh waves is deduced quantitatively from the resonance spectrum. The experimental results demonstrate that the laser ultrasonic techniques is helpful for characterizing surface acoustic waves on elastic scatterers.

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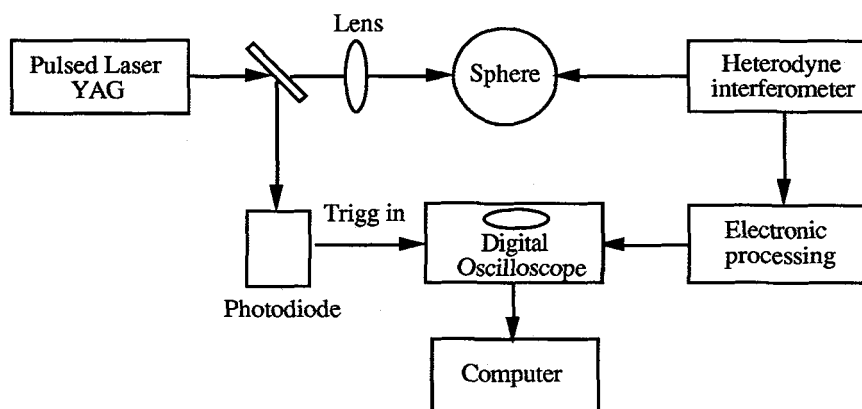


Fig.1. Experimental arrangement of pulsed laser generation and interferometric detection of surface acoustic waves on a sphere

n	Resonance frequency (MHz)		n	Resonance frequency (MHz)	
	Measured	Predicted		Measured	Predicted
1	---	---	11	0.625	0.6220
2	0.137	0.1384	12	0.674	0.6716
3	0.205	0.2058	13	0.723	0.7210
4	0.264	0.2636	14	0.771	0.7703
5	0.322	0.318	15	0.820	0.8195
6	0.371	0.3700	16	0.869	0.8687
7	0.420	0.4213	17	0.918	0.9178
8	0.469	0.4720	18	0.967	0.9668
9	0.527	0.5223	19	1.016	1.0158
10	0.576	0.5722	20	1.065	1.0648

Table I. Experimental and theoretical resonance frequencies of Rayleigh waves on a stainless-steel sphere ($V_L=5.99$ km/s, $V_T=3.29$ km/s) of diameter 20mm

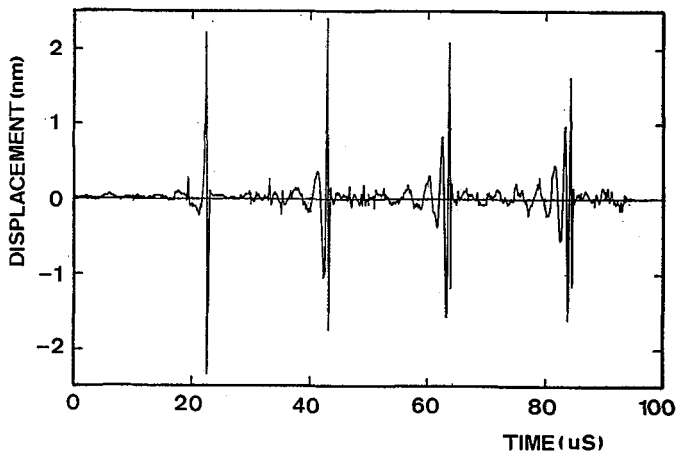


Fig. 2 Optically probed transient displacement of Rayleigh waves on a stainless steel sphere of diameter 20 mm.

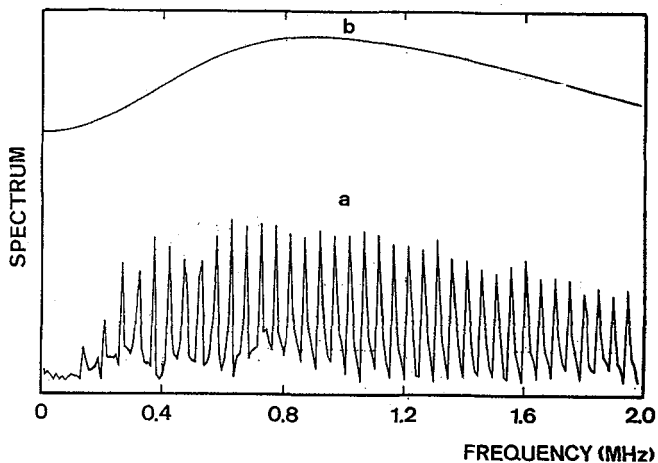


Fig. 3 Fourier transforms of the whole signal in Fig. 2 (a) and of the first echo (b).

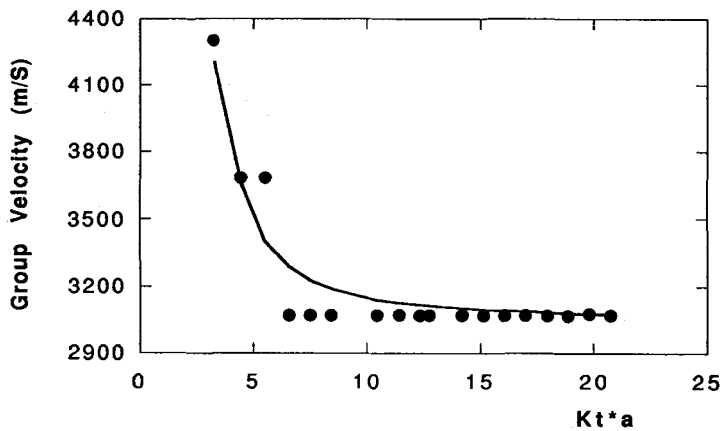


Fig. 4 Theoretical and experimental (O) group velocities of Rayleigh waves on a stainless steel sphere versus the product of shear wavenumber by sphere radius