MEASUREMENT OF SURFACE ACOUSTIC WAVE USING AIR COUPLED TRANSDUCER AND LASER DOPPLER VIBROMETER

Weitao Yuan[1], Jinfeng Zhao[1*], Dongbo Zhang[1], Zheng Zhong[1]

[1] School of Aerospace Engineering and Applied Mechanics, Tongji University, 100 Zhangwu Road, Shanghai, China, jinfeng.zhao@tongji.edu.cn

Keywords: air-coupled transducer, laser doppler vibrometer, surface acoustic wave.

ABSTRACT

To evaluate the out-of-plane displacement of surface acoustic wave, an air-coupled transducer is used to excite surface acoustic waves on an aluminium block, while another air-coupled transducer is adopted to record the leaky waves in association to the out-of-plane displacement. Measurements derived from the air-coupled ultrasonic method have good accordance as compared to the results attained by using a laser Doppler vibrometer. Considering the merits of low cost and safety, air-coupled ultrasonic method has good application prospects in future.

1 INTRODUCTION

Non-contact measurement techniques can be used in many complex testing environments because of their broad advantages, such as high precision, quick dynamic response and demanding no coupling agent [1]. Typical non-contact measurement techniques include the laser triangulation, eddy current method and ultrasonic measurement etc. Among them, the ultrasonic measurements have the merits of strong penetration ability, low cost and safety so that it is used in this paper.

To reduce the loss of ultrasonic waves into air, traditional ultrasonic methods use coupling agent or water immersion so that ultrasonic transducers keep always in contact with the target object. This hinders their applications to certain extend. As an alternative choice, the air-coupled ultrasonic methods (ACUMs) is free from this, much thanks for the development of air-coupled transducers (ACTs) that are used to both generate and receive acoustic/elastic waves [2]. An impedance matching layer with a quarter-wavelength thickness is added to the outer surface of the conventional piezoelectric ceramic ultrasonic transducer, leading to the ACTs with high efficiency and high sensitivity that are ideal for non-contact measurement [3-5]. As the ACTs can be maintained in long distance with the studied object and have the characteristics of non-invasive, non-destructive and loser cost, ACUMs have good application prospects. In general, the configuration of ACUMs includes the pulse echo detection, transmission detection, oblique incidence ipsilateral /dis-side detection and etc.

To validate the ACUMs, the optical measurement namely laser Doppler vibration measurements (LDVMs) is used as well. Based on heterodyne technique and doppler shift effects, LDVMs has high precision, high spatial resolution and high dynamic response, making it suitable for measuring the out-of-plane displacement [6,7].

In this paper, we firstly used ACUM to measure the out-of-plane displacement of surface acoustic wave. And the comparison is given later to the results using LDVM. Good agreement is found between the results derived from these two different methods.

2 EXPERIMENTAL PRINCIPLE

As shown in figure 1, an ACT is used to issue ultrasonic pulses over an oval region on the surface of solid matrix. Consequently, the longitudinal wave, Lamb wave or surface acoustic wave modes can be stimulated on adjusting the incident angle θ_I .

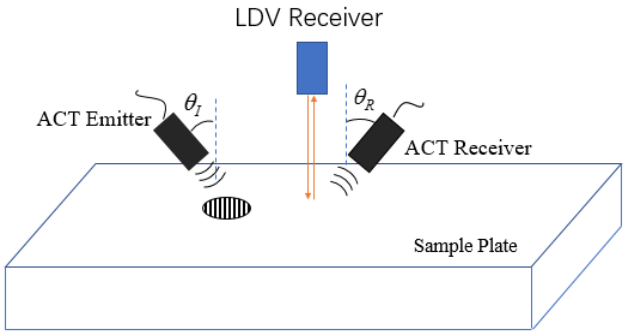


Figure 1: The schematic diagram of emitter and receiver.

To generate Rayleigh wave, one needs setting the incident angle θ_I to satisfy the relationship derived from Snell's law that states

$$\theta = \sin^{-1}(s_x \bullet c_a) \ , \tag{1}$$

where s_x is the slowness of Rayleigh wave, and c_a is the sound velocity in the air.

Another ACT is used as a receiver to record the leaky waves accompanying the the out-of-plane displacement of Rayleigh wave as long as it propagates on the surface. Hence, the receive angle θ_R maintains the same relationship defined by the above equation but with different direction.

The laser Doppler vibrometer (LDV) based on doppler shift effects is used as the receiver as well. In any form of wave propagation, the frequency is altered by the motion of the source, receiver, medium or the motion of scatterer. Austrian scientist Doppler firstly studied this phenomenon in 1842, and then in 1905 Einstein noted that light has similar Doppler shift effects [6,7]. As shown in figure 1, laser beam from LDV directly impinges the surface of the studied object, then the vibration amplitude and frequency can be obtained from the doppler shift of the reflected laser beam. When the incidence and reflection angle both equal to 0°, the doppler shift can be written as

$$\nu' = \nu \frac{1+\frac{V}{c}}{\sqrt{1-\left(\frac{V}{c}\right)^2}} \ , \tag{2}$$

where ν is the frequency of wave source, V is the velocity of the object and c is the velocity of laser beam. The frequency received by LDV shall be expressed as

$$\nu'' = \nu' \frac{1+\frac{V}{c}}{\sqrt{1-\left(\frac{V}{c}\right)^2}} \ . \tag{3}$$

Then the difference of frequency between the source laser beam and the reflected laser beam is

$$\Delta\nu = \nu'' - \nu = \frac{2\nu}{c-V} V \ . \tag{4}$$

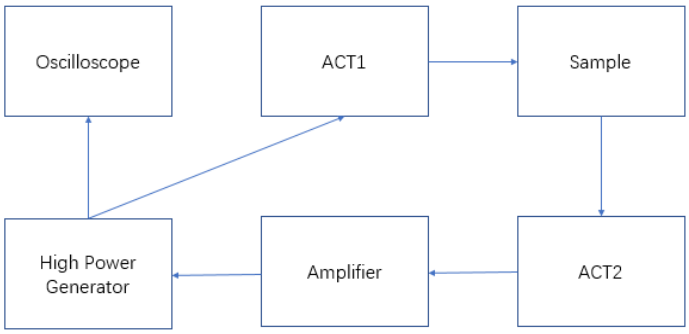
Since $V << c$, we can simplify the above equation into

$$\Delta\nu = \frac{2}{\lambda} V \ , \tag{5}$$

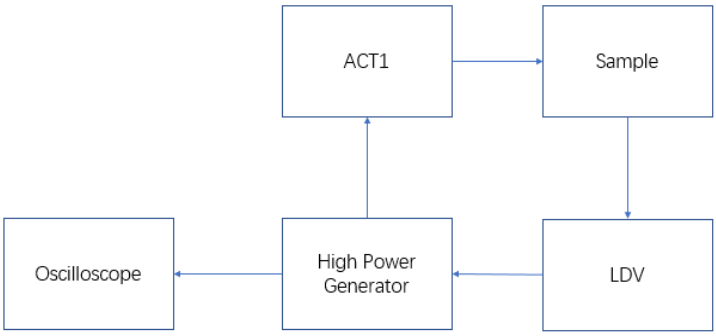
where λ is the wavelength of source laser beam. Since the integral of V is the displacement, the out-of-plane displacement can be obtained by integrating the formula above.

3 EXPERIMENTAL SETUP

From figure 2, one sees the schematic diagrams of the experimental setup used in this work. An ACT, labeled as ACT1, is used to excite surface acoustic wave for both ACUMs and LDVMs. It features the radius *r=16mm*, the central frequency $f_0 \approx 180\ kHz$ and the band width *~30%*. ACT1 is attached to a high-power generator JPR-600C that generates the five cycle ultrasonic pulses. It is noted that JPR-600C has the ability of generating rectangular wave pulses with carrier frequency changing from 30 kHz to 10 MHz and voltage varying from 10 V to 600 V. Then acoustic waves generated by ACT1 go to the surface of aluminum block, with an incident angle calculated by Snell's low as shown in section 2. In return, Rayleigh wave can be generated on the surface of aluminum block.



(a)



(b)

Figure 2: Schematic diagrams of experimental setup: (a) setup using ACT; (b) setup using LDV.

Firstly, we use ACT to measure the out-of-plane displacement of surface acoustic wave, and an amplifier between ACT2 and JPR-600C is necessary, as shown in figure 2(a). Then we use LDV (Polytec vibrometer OFV 2570) to measure that as well.

Then the signals of reference and reflection waves are all connected to an oscilloscope (Digital Phosphor Oscilloscope, DPO 4102B). At each point, the average value of signals of 512 scans are recorded and finally digitized with a sampling frequency of 2.5 GHz. In this way, we obtained signals with good signal to noise (S/N) ratio on the surface of aluminum block free from any inclusions at the points the same distance far away from the ACT1.

4 RESULTS

We measured the out-of-plane displacement of surface acoustic wave using ACT and LDV respectively. The results measured using ACT with excitation voltage 600 V and excitation frequency 200 kHz are shown in figure 3. It is clear that there are five peaks with good S/N ratio. The results measured using LDV with excitation voltage 300 V and excitation frequency 200 kHz are shown in figure 4, it also has five peaks but with more noises.

From these two figures, it is observed that the results measured using ACT have better S/N ratio. This may be due to the fact that the displacement measured using ACT is the average value of signals over an area that are comparable to the surface of ACTs here, so that the white noises can be balanced to certain extend; secondly the amplifier between ACT2 and JPR-600C has the function of filtering noises. It is also observed that the amplitude of the results measured using ACT is larger just due to the existence of the amplifier about ~60 dB before recording signals. There is also difference of the arriving time of primary pulses: in fact, the leaky waves have to go through the distance from the surface of aluminum block to the surface of ACT2 and the sound velocity in air in much smaller than light. The propagation of leaky waves in air need more time than laser in air, so that the arriving time is always later by using the ACT for the measurement. Anyhow, it is obviously that the shape of the waveform is almost the same, in other words, it is conserved.

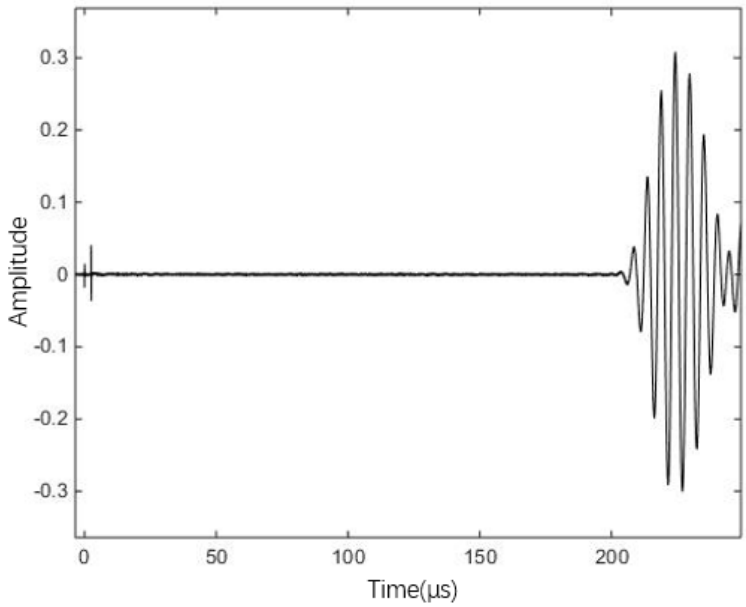


Figure 3: The response measured using ACT

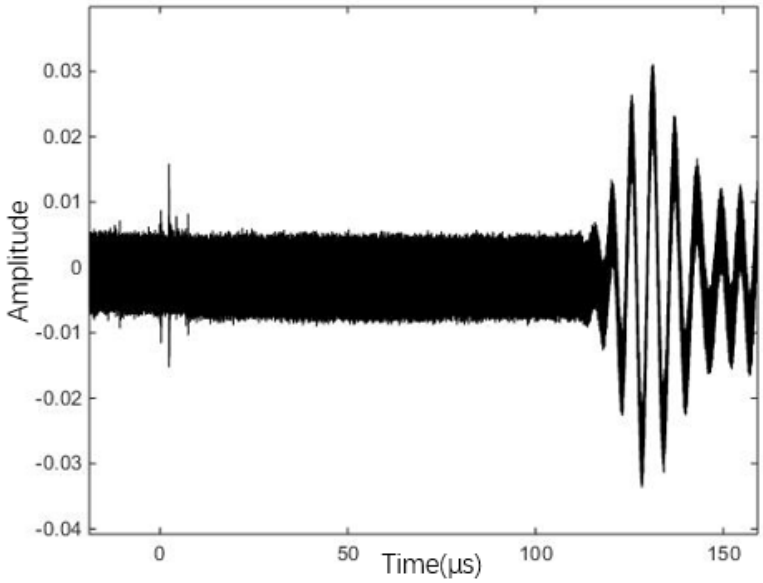


Figure 4: The response measured using LDV

Furthermore, we described the frequency spectrum of the results derived from the measurements by using ACT and LDV respectively. Figure 5 shows the frequency spectrum of the signals in relate to

ACT. It is observed that the frequency is centered on 193kHz. Figure 6 shows the frequency spectrum of the signals measured using LDV, where the frequency centered on 174kHz, featuring a little frequency shift with respect to the excitation frequency. It is clear that the measured central frequency is between the central frequency of ACT 180kHz and excitation frequency 200kHz when using ACT. But it is below 180kHz when using LDV.

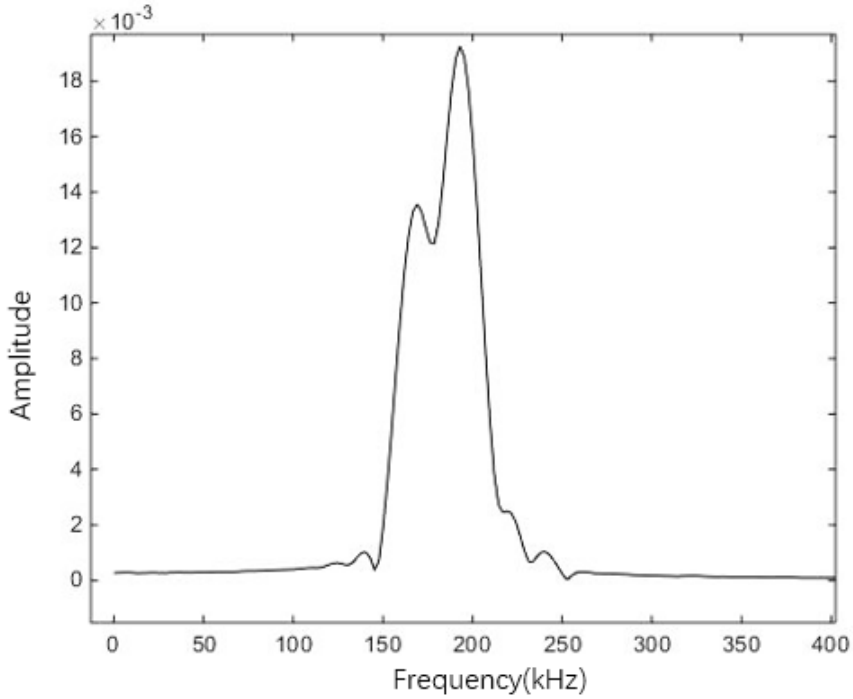


Figure 5: The frequency spectrum of the signals measured using ACT.

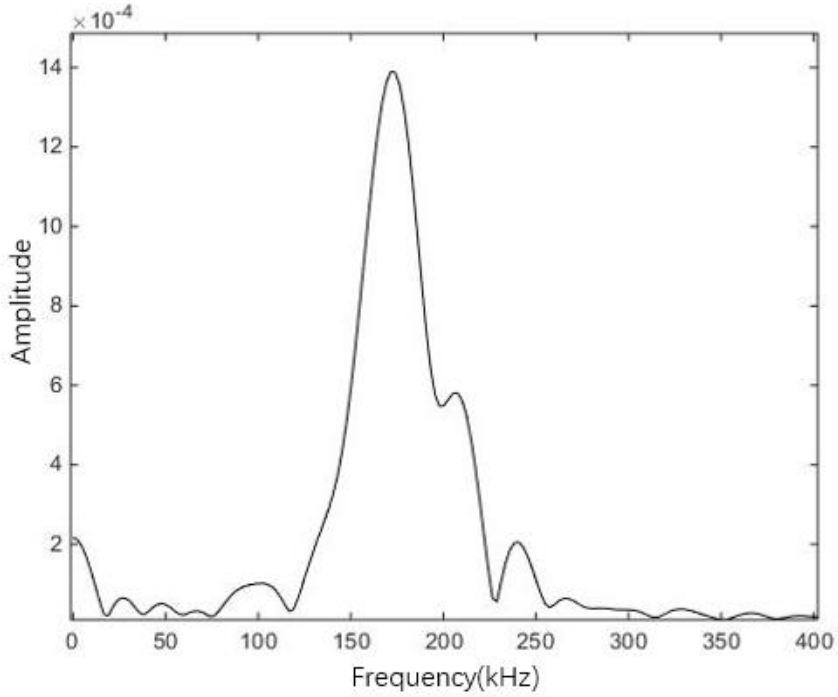


Figure 6: The frequency spectrum of the signals measured using LDV.

5 CONCLUSIONS

We established an experiment setup with non-contact measurement technology to measure the out-of-plane displacement of surface acoustic wave using air-coupled transducer, and compared the results with optical measurement using laser Doppler vibrometer. We found that measurement using air-coupled transducer has good accuracy in comparison to optical methods. Air-coupled ultrasonic method using air-coupled transducer may has good application prospect.

ACKNOWLEDGEMENTS

This work is supported by the financial support by the National Natural Science Foundation of China under Grand No. 11602174 and the Young Scholar Program of Tongji University under No. 1330219167.

REFERENCES

[1] R.E. Green Jr., *Non-contact ultrasonic techniques*, Ultrasonics, 42, 2004, pp9-16 (doi: 10.1016/j.ultras.2004.01.101).

[2] D.E. Chimenti, *Review of air-coupled ultrasonic materials characterization*, Ultrasonics, 54, 2014, pp 1804–1816 (doi: 10.1016/j.ultras.2014.02.006).

[3] Junho Song and D.E. Chimenti, *Design, Fabrication and Characterization of a Spherically Focused Capacitive Air-Coupled Ultrasonic Transducer*. International Journal of Applied Science and Engineering, 4, 2006, pp 1-19.

[4] M.S. Harb and F.G. Yuan, *A rapid, fully non-contact, hybrid system for generating Lamb wave dispersion curves*, Ultrasonics, 61, 2015, pp 62-70 (doi: 10.1016/j.ultras.2015.03.006).

[5] M.S. Harb and F.G. Yuan, *Non-contact ultrasonic technique for Lamb wave characterization in composite plates*. Ultrasonics, 64, 2016, pp 162-169(doi: 10.1016/j.ultras.2015.08.011).

[6] L. E. Drain, *The laser Doppler technique*, Wiley, Chichester, 1980.

[7] B. M. Watrasiewicz and M. J. Rudd, *Laser Doppler measurements*, Butterworths, London, 1976.