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Time-frequency-energy analysis of ultrasound waves generated and detected by laser: application to quality control

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Abstract

Ultrasounds are generally used in non-destructive testing (NDT) with sensors working with a narrow bandwidth. The optical sensors generate and detect acoustical waves without contact and allows measurements in a wide band of frequencies. From this fact, the information contained in the signal captured is complete and give informations (celerity calculated by the time arrival of acoustical waves, attenuation and defect presence). The time-frequency-energy analysis is efficient for the acoustical waves comportment analysis in samples.

Résumé

Les ultrasons sont utilisés classiquement en CND avec fluide de couplage à des fréquences fixes déterminées par les capteurs eux mêmes. Des moyens optiques ont été utilisés pour générer et détecter les ultrasons sans contact, et dans une large bande de fréquence. De ce fait, les renseignements contenus dans un écho sont riches, outre la célérité déterminée par temps de parcours des ondes acoustiques, il est possible d'obtenir des données concernant l'atténuation ou la présence de défauts. L'analyse temps-fréquence-énergie est efficace pour étudier le comportement acoustique des ondes dans un échantillon.

1. Introduction

The generation and detection of ultrasounds by laser are the subject of studies in the behaviour of laser matter and it associated technologies. Although an interferometer sensor by its principle (Michelson, fabry-Perot, Mack-Zehnder) detects a speed and an elongation, the behaviour at the emission is much more delicate. In fact, the optical wavelength of the emitter, the nature of the material, the state of the surface, the angle of incidence, and rugosity (roughness) all have an influence. Previous studies [1] have shown that a CO₂ TEA impuls energy source of 60 mJ and of pulse duration of 90 ns can produce at the focal point an acoustical signal for different types of material even with surfaces of high rugosity or covered with deposits [2]. In that frame work a

source produces, depending on its energy density, either a thermoelastic state generating ultrasound waves with transversal dominance, or a state of micro-ablation generating waves with compression dominance.

2. Experimental method

Research on the effects produced by a fault can be conducted in different ways. In that framework, we have chosen to study the acoustical behaviour of targets with or without defects whose dimensions vary in comparison with different cases. In so doing, the measurement set-up must include three essential elements (figure 1) :

- The emission produced by a source of 60 mJ of energy lasts 90 ns, with an average peak power of 0.66 MW. The energy density is of the order of many hundreds of KW/mm². The micro-ablation mode is obtained at the focal point without destruction problems detectable with the naked eye, which is not generally constricting for elements of general mechanics ;
- The data acquisition is done with an electronic board sampling at 24 MHz, with a memory of 64 Kbytes. The highest ultrasound frequency is 10 MHz which is sufficient in very many NDT applications.
- The signal analysis is done as follows :
 - Preliminary numerical filtering if required ,
 - Determination of the path time of the first echo coming either from the end of the tested part, or from a diffusion on a fault ;
 - Time-frequency-energy analysis [3-6] in order to establish the influence of the fault.

3. Experimental results

We have used a duralumin part of 100 mm in length and 20 mm in diameter, with a drilled through hole at 60 mm of the emission point. The reception is done with an interferometric sensor at the base of the cylinder opposite to the emission point (Figure 1). The acoustical signals with or without defects have been filtered with a triangular band-pass filter [0.2-5 MHz] (Figure 2).

We have been interested in a fast method of quality control where the positioning and dimensioning of a defect is expected. We have studied spectrum differences in the time-frequency-energy space based on the sliding window Fourier Transform (SWFT) which uses rectangular-window functions. The algorithm consists in cutting the signal into successive time slices and to apply a standard "Fast Fourier Transform" (FFT) on each slice. The spectral contents are then obtained within the window interval (fixed at the beginning). The SWFT is then computed by translating that window along the time axis. The introduction of a fault eliminates some of the waves generated by the mode conversion. The discrete longitudinal wave is transformed in a diffusion wave. The discrete

transversal wave is then time shifted and becomes the first wave due to the fault following the diffusion wave (Figure 3). The spectrum difference from the SWFT enhances the effect of the fault.

The speed at which this result is obtained makes this analysis method practical in fast quality control. The time at which the anomaly appears shows a possibility of the positioning or locating an impedance rupture at the origin of the echo. The theory of resonance can be used to dimension the faults (holes). It allows to link resonance frequencies caused by a hole to its size through a constant which is equal to the celerity (speed) of the compression waves going through the fluid filling the hole.

4. Conclusion

The laser ultrasound technique has been efficient for conformity detection. In this work, we have used the generation mode by micro-ablation which gives a good acoustical level. The time-frequency-energy analysis combined with filtering methods allows to evaluate the conformity of parts to be tested through the SWFT spectrum difference between good and bad parts.

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Figure 1
Measurement set-up

(a)

(b)

Figure 2
Acoustical signatures (a) without fault, (b) with fault of 3 mm in diameter
(cylinder in duralumin : $l = 100$ mm, $D = 20$ mm)

(a)

(b)

Figure 3
3-D SWFT analysis (a) (etc)

Figure 4

SWFT spectrum difference between a part without fault and a part with fault of 3 mm in diameter, cylinder in duralumin : $l = 100$ mm, $d = 20$ mm.