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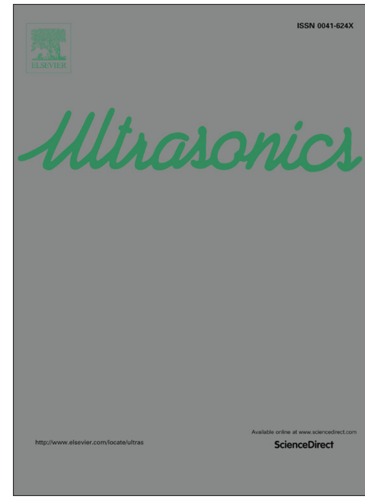

Evaluation of crack parameters by a nonlinear frequency-mixing laser ultrasonics method

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PII: S0041-624X(16)30015-4
DOI: http://dx.doi.org/10.1016/j.ultras.2016.04.005
Reference: ULTRAS 5253

To appear in: *Ultrasonics*

Received Date: 30 September 2015
Revised Date: 29 March 2016
Accepted Date: 4 April 2016

Please cite this article as: S. Mezil, N. Chigarev, V. Tournat, V. Gusevs, Evaluation of crack parameters by a nonlinear frequency-mixing laser ultrasonics method, *Ultrasonics* (2016), doi: http://dx.doi.org/10.1016/j.ultras.2016.04.005

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Evaluation of crack parameters by a nonlinear frequency-mixing laser ultrasonics method

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Abstract

The local evaluation of several parameters of a crack is realized with a nonlinear laser ultrasonic method. The method is based on the sample excitation by two laser beams, independently intensity modulated at two cyclic frequencies ω_H and ω_L ($\omega_H \gg \omega_L$) and on the detection of nonlinear frequency-mixing ultrasonics components at frequencies $\omega_H \pm n\omega_L$ (n an integer). Frequency-mixing is a nonlinear process originating from the modulation of the crack state at low frequency ω_L by laser-induced thermo-elastic stresses, which causes in turn the modulation of the acoustic waves at frequency ω_H reflected/transmitted by the crack. We carry experiments with increasing laser power and observe a non-monotonous variation in the amplitude of up to 6 nonlinear sidelobes. We also improve a previously introduced theoretical model which leads to interpreting the experimental observations to the combined action on the crack of the thermo-elastic waves at low frequency ω_L and of the stationary thermo-elastic stresses at $\omega = 0$. The latter are induced by the average laser power absorbed by the sample. While thermo-elastic wave can periodically modulate the parameters of the crack up to its periodic opening/closing, the stationary heating could cause complete local closure of the crack. By fitting the experimental amplitude evolutions for all monitored sidelobes with the theoretically predicted ones, various local parameters of the crack are extracted, including its local width and effective rigidity.

Keywords: Laser ultrasonics, Nonlinear acoustics, Nondestructive testing, Cracks, Photoacoustics, Frequency-mixing

1. Introduction

Microstructures or defects in elastic solids such as cracks, delaminations, inclusions, grains..., have been demonstrated to be sources of high nonlinearities [1,2,3]. These nonlinearities are much higher than those of homogeneous elastic solids. Taking advantage of this property, numerous nonlinear acoustics methods have been developed in order to increase considerably the sensitivity to defects in comparison to linear methods. Harmonic [4,5,6,7,8,9,10] or subharmonic generation [5,11], for example, are commonly used. However, most of these techniques are used only for crack detection applications and are not commonly providing quantitative information on the parameters of the crack.

Theoretical models demonstrate that the contact between two rough surfaces, and therefore between crack faces, is an efficient source of nonlinearities [12,13,14,15,16,17]. In particular, the amplitude of the harmonics as a function of the vibration excitation is highly non-monotonous if the crack evolves between an open state (crack faces are not in contact) to a closed one (crack faces are in contact). In fact the amplitudes of the higher harmonics depend on the parameter characterizing the ability of the acoustic wave to modify the crack state. This parameter could be for example the ratio of the crack face displacement imposed by the acoustic wave to the crack width/opening or the ratio of the characteristic stress in the acoustic loading to the static stress required for complete closing of the crack. It appears that as a function of such parameter, the harmonic amplitudes could have pronounced minima [12]. The amplitude of a sinusoidal acoustic excitation for which a particular higher harmonic is not generated depends on the parameters of the crack such as its opening. Thus, controlling and varying experimentally the amplitude of the

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