ON THE USE OF GUIDED ULTRASONIC WAVES IN NONDESTRUCTIVE DIAGNOSTICS AND FAILURE ANALYSIS

Peter Hess$^{1(*)}$, Alexey M. Lomonosov$^2$, Andreas P. Mayer$^3$

$^1$Institute of Physical Chemistry, University of Heidelberg, Heidelberg, Germany
$^2$General Physics Institute, RAS, Moscow, Russian Federation
$^3$HS Offenburg - University of Applied Sciences, Gengenbach, Germany

(*) Email: peter.hess@urz.uni-heidelberg.de

ABSTRACT

Advanced ultrasonic detection techniques are presently developed for applications in all three dimensions (1D-3D) employing conventional transducers and laser methods. In practical applications predominantly versatile piezo-transducers and interdigital structures are used, while scientific research and development are mainly based on contactfree laser methods. Examples are given for the use of guided bulk waves (3D) in monitoring pipes and rails, linear and nonlinear surface acoustic waves (2D) in NDE and failure analysis, and the present development of linear and nonlinear wedge waves (1D) as new diagnostic tools.

Keywords: conventional and laser ultrasonics, guided bulk, surface, and wedge waves, NDE, fracture strength.

INTRODUCTION

Nondestructive evaluation (NDE) and structural health monitoring (SHM) to evaluate materials properties without causing damage and the determination of critical fracture stresses or real strengths of materials to avoid catastrophic structural failure play an ever increasing role in materials science and technology. One of the upcoming advanced tools besides conventional ultrasonics is laser ultrasonics, suitable for pulsed excitation and continuous-wave detection of guided one-, two, and three-dimensional (1-3D) elastic waves with high spatial resolution in contactfree manner. The most important features of the use of lasers are access to nonlinearity and destructive testing based on high laser power. This allows the determination of the real engineering strength of materials and comparison with the ultimate theoretical limits of mechanical behavior.

BULK WAVES

Even in well-established practical applications of conventional ultrasonics with 3D bulk waves to macroscopic objects such as rails or tubes, there is a tendency to use guided waves for industrial inspection, which is connected with reduced cost, less inspection time, and greater coverage. These guided ultrasonic waves are constrained by the boundaries of the particular geometric structure and include, for example, torsional waves in a tube or Lamb waves in a plate but also longitudinal or shear modes. A serious challenge of guided modes in complex geometries is their dispersive and multimode nature. Thus, substantial computational effort is needed for data analysis under these conditions. Dispersion occurring in these pseudo 1D waveguides usually inhibits generation of harmonics higher than second harmonics. Permanent sensor installation for long distance diagnostics by piezo-transducers, e.g. in rails, is a new approach in SHM. For 3D applications laser ultrasonics is still under development.
SURFACE WAVES

Surface acoustic waves (SAWs), first discovered by Lord Rayleigh in 1885, can be characterized by a 2D wave vector. The planar surface of an elastic half space is a 2D waveguide for these particular waves. The displacement field decays to zero in the direction normal to the surface within about one wavelength depth. SAWs or Rayleigh waves are non-dispersive in homogeneous media. In recent years laser photoacoustics opened the door to many new applications of linear SAWs such as NDE of surface-breaking cracks. Real partially closed surface cracks of micrometer size have been analyzed with this method. Beside defect analysis laser pump-probe experiments allow the excitation of short nonlinear SAW pulses with steep shocks that fracture brittle materials such as silica or silicon. With such a laser-based method it is possible to measure the fracture strength of materials and compare the critical failure stress with ab initio calculations of the theoretical strength of the ideal single crystal, defining the corresponding upper limit of the mechanical strength. This allows the judgement of the mechanical quality and strength of engineering materials. Of particular interest is the comparison with the ultimate limit of mechanical behavior realized in 2D solids such as graphene.

WEDGE WAVES

The acoustic edge or “wedge waves” (WWs) were discovered in 1972 by numerical calculations. Theoretical approaches prove the existence of these real 1D acoustic waves with 1D wave vector along the edge also in anisotropic crystals. The displacement field decays exponentially away from the tip in the plane normal to the edge. The selective excitation of these guided waves was performed with an optically-pumped angle-tunable transducer. Their non-dispersive nature in ideal wedges, the lack of coupling with Rayleigh and bulk waves, and the very high degree of localization of this new type of elastic waves make them suitable for NDE. Based on the extreme localization of strain a stronger nonlinear behavior is found than for SAWs and bulk waves. This opens the door to the new field of 1D waveguides with pronounced nonlinear behavior. Currently, linear, leaky, and nonlinear SAWs play a significant role in controlling fluids and particles in lab-on-a-chip devices with their applications in chemistry, biology, and medicine. The strongly guided linear, leaky, and now also nonlinear WWs open a new frontier for applications of low-dimensional guided acoustic waves with even higher spatial resolution in topographic structures.

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REFERENCES