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Theoretical and experimental investigations of Lamb waves excitation and their diffraction by surface obstacles

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Structural health monitoring techniques for inspection of plate-like structures based on ultrasonic Lamb waves are getting more and more into the focus of research. The Lamb waves propagate along the plate for great distances and may be reflected by any inhomogeneities. In recent years a large and increasing number of publications is observed relating to the theoretical and experimental investigations of elastic wave diffraction at defects of different kind (surface cracks, notches, holes and so on) in isotropic and composite plates (e.g. [1, 2] and cited papers). In many practical applications the structure contains surface inhomogeneities such as rivets, bulges, welding deposition, etc. Another important problem is to choose suitable devices for the elastic wave actuation. In recent years piezoceramics, which could be applied both as input and output devices, became widespread since they are cheap, easy to use and can also become an integrated part of a monitored structure.

In the course of joint research work a series of experimental measurements has been carried out accompanied by theoretical computer simulations which aimed at the investigation of piezoelectrically induced Lamb wave propagation and diffraction at different surface obstacles. The proposed model allows proper interpretation of the damage detection results for complex structures.

The theoretical modeling has been performed in the context of general linear elasticity. Using the causality principle for linear systems transient displacements of a stress-free elastic isotropic layer with surface obstacles are expressed through their time-harmonic spectra which are obtained from the boundary value problem (BVP) for the full system of Lamé-Navier equations. The following types of obstacles are considered: immovable obstacles (clamped surface portions) and massive rigid or elastic bodies rocking together with the plate under the Lamb wave incidence. The latter is modeled by the integral and asymptotic representations in terms of Green's matrix of the structure under consideration and surface traction induced by piezopatches [3]. The model of the piezoactuator actuator can be found in [4]. The scattered wave fields are described by similar integral representations, which involve unknown contact stresses caused by incident waves. Their distribution is obtained from the Wiener-Hopf type integral equations using expansion in terms of specially constructed axially symmetric delta-like functions [3, 5]. In contrast to the conventional finite element technique, where discretization of the whole 3D domain is required, only contact and load areas are discretized in the models developed. It reduces the computational costs sufficiently. Moreover, since the approach used is based on 3D BVPs, it allows one to obtain relevant results for both low and high frequencies in contrast to approximate plate theories that are only applicable in low frequency ranges.

The experimental investigations have been performed with an isotropic aluminium plate of 1 mm thickness. Circular piezoactuators are used as a wave source while the data are recorded using the laser-vibrometer technique. The following obstacles are used: permanent magnets placed from both sides of the plate, pieces of steel glued to the aluminium plate and drops of molten solder placed on the surface. At first, a series of numerical calculations combined with experimental tests were performed for the plate without obstacles. Two examples of their comparison are shown in figure 1. The piezoactuator is driven by two-cycle sine toneburst windowed by sine function with central frequencies $f_c = 50$ and 100 kHz (left and right subplots, respectively). Figure 2 gives an example of Lamb wave diffraction by an obstacle measured by laser vibrometer (left) and computed using the model developed (right). The obstacle is added to the plate by putting two massive round magnets of diameter 14 mm at the distance 106 mm from the source. The numerical results are for the immovable (clamped) contact surfaces. The scanning area is 100 mm$\times$100 mm. A very good agreement of the experimental and theoretical results for both incident and diffracted fields is observed.

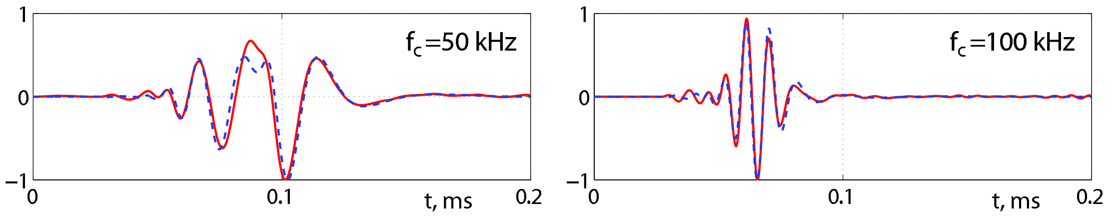

Figure 1: Experimental (solid line) and computed (dashed line) normalized vertical velocity component at the monitoring point 70 mm away from the actuator.

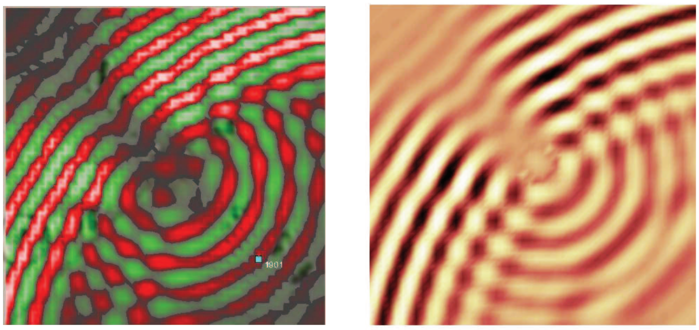

Figure 2: Experimental (left) and computed (right) scans of vertical velocity component; $f_c = 100$ kHz.

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