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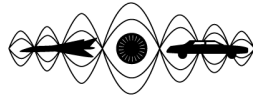
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MODELING FOR NONLINEAR LASER VIBROMETRY EXPERIMENTS IN SOLIDS WITH FRICTIONAL CRACKS

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Modeling for processes underlying NDT and SHM by ultrasound and vibrations present certain benefits. A valid digital tool can help accept or reject a hypothesis on damage position, orientation and degree of gravity. As a final objective, a fully reconstructed damage configuration can supplement diagnostics by prognostics and help describe future evolution of damage in certain conditions. To do so, as a first step it is necessary to have a tool capable of describing acoustic waves in materials with inner contacts (cracks, delaminations, loose joints) with the account for a most pertinent phenomenon occurring in there, friction. Frictional interfaces have complex hysteretic response that depends on history of excitation. It is suggested to describe this response by using an original semi-analytical method of contact mechanics called the Method of Memory Diagrams (MMD). The MMD provides boundary conditions at crack faces necessary for the wave propagation description modeled via standard FEM software. The next step is a qualitative imitation of a nonlinear acoustic NDT experiment via the proposed model. Here we have implemented the MMD-FEM principle in a 2D case similar to the one typical for nonlinear laser vibrometry experiments. A piece of plate containing a frictional crack parallel to the surfaces is excited with a harmonic signal. Contact nonlinearity of the defect generates higher harmonics, in particular, in the normal displacement field at the top surface measurable in real vibrometry experiments. We show that the spatial harmonics' distribution indicates the position and the size of the crack.

Keywords: contact acoustic nonlinearity, friction, crack, NDT, laser vibrometry

Extended abstract

Even in the 21st century, modelling for acoustic behaviour of materials and structures containing frictional crack presents serious challenge. An obvious factor is related to the necessity to imitate rapid evolutions of distributed mechanical fields (stresses, displacements) in structures of special geometries. As an example, in our 2D simulations, even without cracks, the ratio between the calculation time and the real time of acoustic propagation makes a value of order of 10^6 for an average personal computer. However, a real difficulty comes from complex hysteric behaviour of cracks related to solid (dry) fric-

tion characterised by a threshold effect which means that, in order to initiate sliding of crack faces, some relation in terms of contact stresses (Coulomb friction law, $|\tau| = \mu\sigma$ for the shear and normal stresses) should be satisfied. To comply with that, any excessive shear stress should be released by assuming some relative tangential displacement which is a priori unknown. This value has to be adjusted in order to have exactly $|\tau| = \mu\sigma$ at that crack fragment. The adjustment produces redistribution of all mechanical fields in the entire sample. If now there are several crack fragments that slide, the adjustment procedure should be set in a way that simultaneously satisfies the Coulomb friction condition in all sliding fragments. In this situation, a costly implicit numerical procedure is required.

The development of semi-analytical methods of contact mechanics based on the Cattaneo-Mindlin (also called Hertz-Mindlin) solution presents an excellent opportunity to avoid this difficulty. The idea consists in the introduction of internal relief of crack faces (roughness) that can be effectively replaced by equivalent axisymmetric contact shapes. Hysteretic contact solutions for such shapes have been generalized recently for any normal and tangential displacement histories. As a result, the arguments and fictions in the load-displacement relationship are flipped, and the contact loads σ and τ are calculated from displacements via an explicit procedure. The details of the method (called MMD, the method of memory diagrams) are given elsewhere [1,2]. Combining the MMD-based boundary conditions and standard finite element software provides the description for acoustic and vibrational phenomena in materials or structures containing crack-like damage [3].

In Figure 1 we show an modelling example that qualitatively imitates a real laser vibrometry experiment. This experimental technique is relatively easy to simulate as it does not require sharp focusing used in other imaging methods such as time reversal or phased array. However, laser vibrometry is usually done via a continuous harmonic excitation that generates a standing wave in a sample.

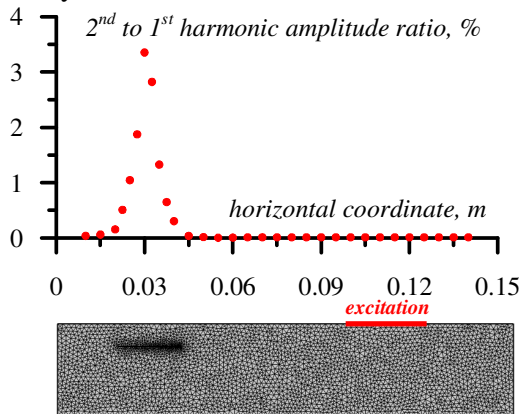


Figure 1: Meshed sample with a crack and distribution of the 2nd harmonic of normal displacement at the top surface.

In that connection, in our first example we assume highly exaggerated damping that exceeds typical values for solids (e.g. metals) by several orders of magnitude. Without imposing considerable changes to the principle, it allows one to build up the standing wave during a reasonable calculation time (about 80 times of flight here). In this extremely viscous solid, the second harmonic of the normal displacement at the top surface clearly indicates the position and the extent of damage (see peak in the curve in Fig. 1 and the mesh refinement zone in the sample that surrounds the crack). This normal displacement is typically measured by a laser vibrometer in this kind of experiments. We plan to further advance our modelling method and seek for quantitative agreement with experiment.

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