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Numerical and theoretical investigations of modulation transfer due to nonlinear shear wave interaction at frictional interfaces

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Abstract: Presented paper investigates the modulation transfer observed for the propagating shear wave due to the interaction with the nonlinear frictional contact interfaces. The analytical results based on the Harmonic Balance expansion, are compared with a numerical approach based on the Local Interaction Simulation Approach (LISA). In the scrutinized case, two source shear wave excitations are considered. First referred as probing wave is a single frequency sine wave, and a second referred as pumping wave is a single frequency sine wave modulated by a sine wave of one-order lower frequency. The excited wave interacts with the nonlinear frictional interfaces, causing a modulation transfer. Interestingly, despite the symmetric characteristic of considered local source of nonlinearity, the transfer of all orders of sidebands is observed.

Keywords: Nonlinear Shear wave, Friction, Modulation, LISA, Harmonic Balance

1. Introduction

The maintenance of engineering structures requires reliable methods for detection and assessment of structural damages and material degradation. Various methods based on elastic waves propagation in solids were proposed and implemented to detect fatigue cracks, delamination, debonding etc. Recently, nonlinear ultrasonic-based methods are of a particular interest, as they offer remarkable sensitivity to broad class of damage related phenomena, at early stages. Incipient defects can be investigated by virtue of classical nonlinear effects such as higher harmonic generation, or non-classical effects e.g. hysteresis, slow dynamics, stress-strain hysteresis, or modulation phenomenon. In particular, the modulation phenomenon draws our attention. First, due to the fact that its is not particular investigated for the shear wave propagation in the structure, and second, the possibility to observe the existence of the nonlinear phenomenon in the close proximity of the excited frequency in a form of side-bands. In this work, a particular case of modulation transfer phenomenon is investigated using a numerical tool based on LISA [1], and a theoretical approach based on Harmonic Balance method (HBM) [2].

In the presented study, propagation of the Shear Horizontal (SH) waves in a linear medium with a local nonlinearity is considered. As a source of the nonlinear phenomenon, the shear stick-slip movement of fatigue crack surfaces is assumed. The faces of the crack interact mechanically by the friction force, which results from the contact between asperities under a normal force. This is implemented in the numerical model as Coulomb friction formulation of crack surfaces behaviour. To facilitate the comparison of LISA and HBM, the crack is modelled as a through-thickness crack localized in the middle of the plate length. In order to observe the modulation transfer, pumping and probing waves are excited simultaneously in the structure by a displacement uniformly distributed over the thickness of the plate.

2. Results and Discussion

The results from two modelling approaches are presented in Fig 1. The pumping wave is a high frequency amplitude modulated acoustic wave with f_1 = 490 kHz and f_m = 21 kHz and the probing wave is monoharmonic acoustic wave with f_2 = 85 kHz.

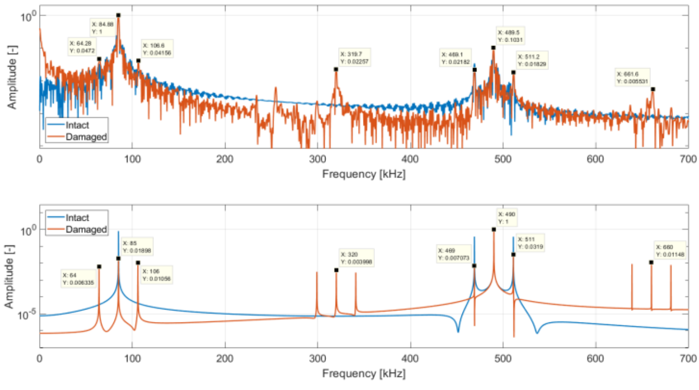

Fig. 1. Numerical results obtained from SH-LISA (top) and HB (bottom) in frequency domain for intact and damaged structures.

In the results of both models, it is possible to distinguish the following terms: the modulation transfer sidebands ($f_2 \pm f_m$), the odd higher harmonics – $(2n+1)f_1$ and $(2n+1)f_2$ – and the mixed terms responsible for the generation of sidebands around the frequency $f_1 \pm 2f_2$.

3. Concluding Remarks

The results clearly indicate that the modulation transfer from the high frequency pumping wave to the probing wave is invariant/insensitive to the type of nonlinearity in the examined structure. Because Coulomb friction is a symmetric type of nonlinearity, in the higher-harmonic generation analysis only odd harmonic are expected. Similarly, in the cross-modulation– f_2 signal modulating f_1 – only even side-bands should appear. These phenomena are observed for the investigated models. In contrast, the f_m modulation components have transferred in all orders, both for LISA and HBM models. This gives a new insight on the conditions of modulation transfer, which depends on the type of source of non-linearity.

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