Synthetic generation of vibroacoustic modulation signals for structural health monitoring

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Abstract

The vibroacoustic modulation (VAM) is a nonlinear ultrasonic testing method that has been the subject of many studies since the 1990s. This method utilizes the modulation of a high-frequency/low-amplitude probe wave with a low-frequency/high-amplitude pumping vibration, resulting in high sensitivities to damages in the structure. However, applying the method outside of the laboratory as a structural health monitoring system for actual structures is challenging, mainly because the ambient vibrations—which would ideally be utilized for the pumping vibrations—are not constant over time regarding amplitude and frequency. To circumvent this, we present a synthetic generation of the VAM signal. In principle, this synthetic signal can be obtained from measurements of the high-frequency response of the specimen, acquired at two (or more) static stress levels of the structure. The signal length of these measurements can be as short as milliseconds, as long as a steady state is reached. We could show that only 16 values (8 measured values of only two stress levels with a sampling frequency of 1/20 of the Nyquist frequency) are required to generate the often calculated Modulation Index with a mean deviation of 0.97 % to the expected dynamic measured values for glass fiber reinforced composites and 1.86 % for the aluminum specimens, which is negligible compared to a typical increase of the Modulation Index of 10–30 dB in case of severe damage. Even undersampled measurements at each stress level can be used without sacrificing accuracy, which reduces the requirements for the sensor nodes. Moreover, this method decouples VAM from the actual need for a constant recurrent frequency and amplitude of the natural vibration in order to reliably compare measurements throughout the lifetime. Hence, this work aims to open the possibility of ultimately applying VAM to assess the structural health of complex structures.

Keywords: Damage Detection, Vibroacoustic Modulation, Structural Health Monitoring, Nondestructive Testing, Nonlinear Acoustics, Lamb Waves

1. GFRP specimen 1

The MI calculated for every frequency of the dynamic measurements is plotted over the frequency and the maximal tensile stress of the specimen in Figure 1 to illustrate the reference for the following synthetic computation of VAM. The measurements of the undamaged specimen, which is the foremost line at a max. stress of 22.2 MPa, shows a frequency dependence of the MI. There are two areas (196 kHz & 205.5 kHz), which are

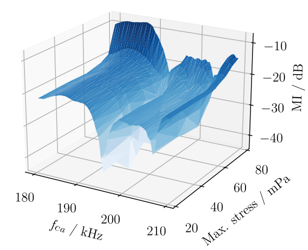

Figure 1: Modulation Index of the dynamic VAM measurement for all frequencies over the applied stress. Except for frequencies near resonances, a significant increase of the Modulation Index for all frequencies due to the inter-fiber cracks is occurring.

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affected strongly by the natural frequencies of the specimen, resulting in minimal modulations due to VAM. Over the first measurements, the MI remains constant. After the load of 54 MPa the first cracks occurs, resulting in an increased MI over the whole frequency range. This increase is only absent in the vicinity of the resonances due to the minimal modulation.