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Ph.D. DISSERTATION DEFENSE

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Title: Vibro-Acoustic Modulation for Crack Detection in Wind Turbine Blades
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ABSTRACT

Wind turbine (WT) blades face environmental stress, causing maintenance costs and blade failure. Vibro-acoustic structural health monitoring (SHM) methods, which analyze structural vibrations of the blade, are used for inspection. However, these methods require comparison between intact and damaged structures, limiting their usage.

Nonlinear vibro-acoustic SHM methods are more sensitive to damage than linear methods. One of these methods Vibro-Acoustic Modulation (VAM) is based on the modulation of high-frequency vibrations by low-frequency vibrations and it suits WT blades due to their periodic load changes from blade rotation.

This dissertation explores high-frequency vibration modulation in blades by low-frequency loads caused by blade rotations. Blade rotation results in bending stress variations, altering the crack size and blade resonance frequency. Two methods for high frequency wave excitations are considered: harmonic wave excited by piezoceramic piezoelectric discs bonded to the blade, and wideband naturally excited blade vibrations. A simple breathing crack model simulates VAM, predicting the dependence of the modulation level on the blade's vibro-acoustic parameters.

The work also includes laboratory tests using VAM with harmonic and wideband probe waves to detect cracks in steel samples under cyclic loading. The number of peak sideband (SPN) observed in a harmonic probe signal test serves as a damage indicator. Results can be simulated by a bilinear crack nonlinearity model. The model shows that the amplitude dependence of SPN on the pump and probe wave amplitudes significantly differs from the quadratic crack model typically used in VAM tests. Tests with a wideband probe signal were conducted. This test was performed on steel under cyclic loading. The received signal's demodulation was conducted using the Detection of Envelope Modulation on Noise (DEMON) algorithm. The experimental results were compared with the VAM with harmonic pump wave. Both the wideband and traditional VAM methods demonstrated similar sensitivity for the early detection of invisible cracks in steel samples.

The considered VAM method for cracks and damage detection in WT blades can be integrated into the currently used SHM monitoring. This integration does not necessitate additional hardware and can utilize signal-processing algorithms to extract the nonlinear effects described in the thesis.

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