Defect detection in composite material by means of photorefractive vibrometry

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The use of composite materials for structural elements in high value structures and components (e.g., wind turbines blades, composite parts in aircrafts …) requires fast and reliable tools for assessing their structural integrity.

The inspection method proposed in this work is based on the detection of defect-induced elastic cross-modulation phenomena using a vibrometric scheme that makes use of photorefractive interferometry. This non-contact method is full-field and aims at inspecting large areas at once and enable detection of defects in an early stage.

The novelty of the system lies in both the acoustic excitation and in the detection method. Two guided waves are sent along the sample: one of low amplitude and high frequency (probe) and one of high amplitude and low frequency (pump). The mechanical response of a damaged composite sample is, in general, not linear. Detection of acoustic frequency mixing caused by mechanical nonlinearity can thus evidence the presence of a crack or delamination defect.

We have exploited non-degenerate two-wave mixing in a photorefractive crystal to perform a full-optical lock-in detection and image the vibration pattern at the frequency of interest, the defect signature, without crosstalk from other vibrations, e.g., from the strong pump vibration, which was used to modulate the defect response to probe vibrations.

Using standard homodyne interferometry, frequency mixing between the modulation frequency and the probe frequency, resulting from the defect response would be indistinguishable from frequency mixing due to the nonlinear relation between the interferometer light intensity and the measured displacements. Heterodyne techniques, on the other hand, do not allow for full field detection. This work highlights that photorefractive interferometry allows for frequency selective detection of vibrations and enables to identify the modulated probing signal amid an intense vibration background.

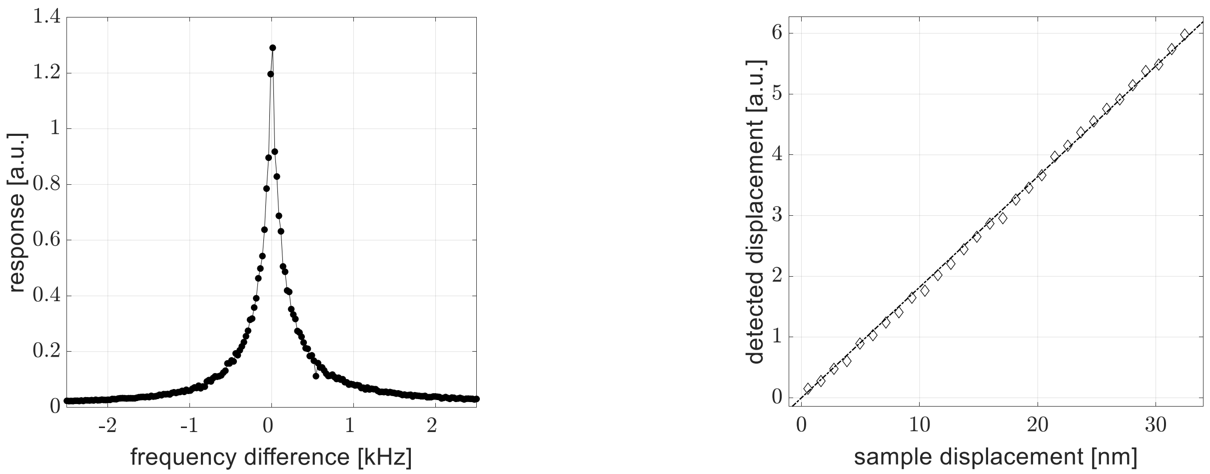

Figure 1, left. PRI response as a function of the frequency difference between the target frequency and the frequencies at which the sample vibrates. The PRI response is that of a bandpass filter. Right, detected displacement as a function of sample displacement. The PRI has a linear response and a minimum detectable displacement of 0.5 nm

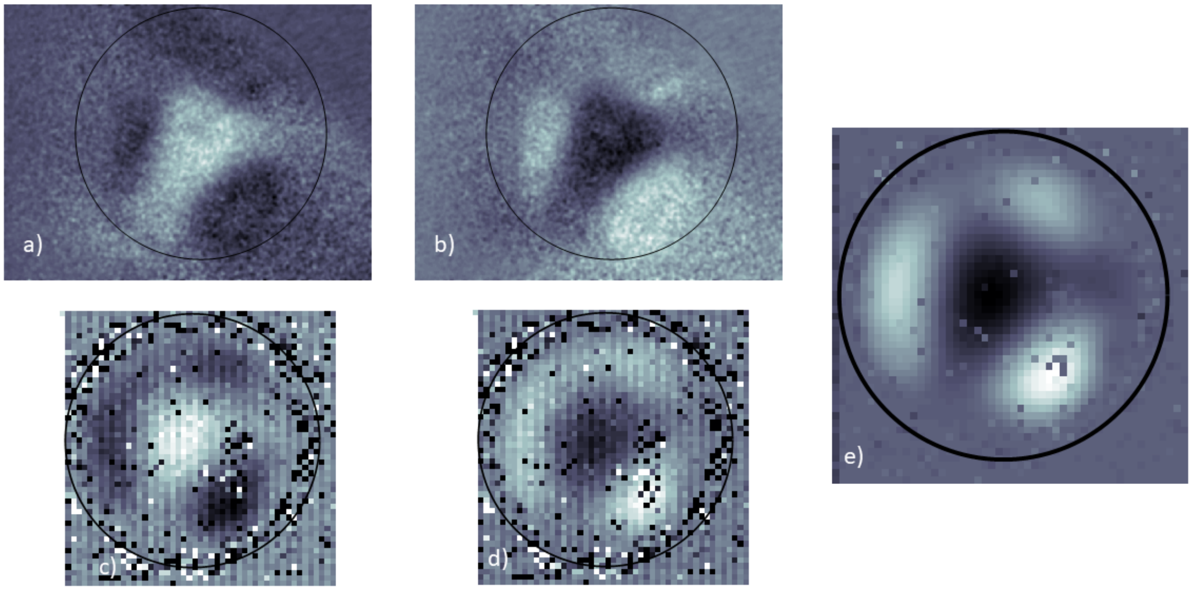

Figure 2 Vibration modes of a brass plate, coupled to a piezo actuator, as imaged by the PRI (a,b) compared to as measured by a commercial laser Doppler Vibrometer (c,d,e). The brass plate is a disc of 4 cm diameter, clamped at the edge (black solid circle). Panels a) and b) snapshots of the vibration pattern at a standing mode of the sample (2400 Hz) at phase= 0° (a) and 180° (b). Panels c) and d) are obtained by scanning the sample with a laser Doppler vibrometer at phase= 0° (c) and 180° (d). Panel e) is the Fourier transform of the laser Doppler scan calculated at 2400Hz. The sample vibration amplitude was 90 nm.