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Fourier-transform vibrothermography with frequency sweep excitation utilizing local defect resonances

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ABSTRACT

The defect activation and detection efficiency of low-energy vibrothermography can be further improved by periodically sweeping the ultrasonic excitation frequency and Fourier-transforming the temperature data at the modulation frequency. This is due to the resulting periodic heat production. While typical local defect resonance investigations make use of known resonance frequencies, this technique instead employs a wideband ultrasonic excitation signal. It can therefore be used to detect defects quickly without knowing the LDR frequency in advance, while still keeping the efficient defect activation effects provided by LDR. Otherwise undetectably low thermal defect signals are enhanced by means of Fourier filtering and the defects' resonance frequencies are characterized by their phase values.

1. Introduction

Vibrothermography is well known for its defect selective, dark-field damage detection capability, yet it is currently only used with bulky high power equipment. In order to advance this method from its current lab status to a reliable and certified NDT-procedure a reduction in energy consumption combined with improved defect activation and signal processing is necessary. One way to achieve this goal is the combination of vibrothermography with the concept of local defect resonance (LDR).

1.1. Local defect resonance

The concept of LDR has been first investigated and described in [1,2]. Local defect resonances occur on the basis that the presence of a defect leads to a local decrease in stiffness for a certain mass of the material in this area. Using a frequency match of the driving ultrasonic source and the resonance frequency of the local defect area leads to a very efficient energy pumping into the defect area. This results in high amplifications of the defect vibration amplitude as compared to the residual sound specimen area. There is a distinct relation between the defect size and its resonance frequency. Eq. (1) was first derived in [2] for cylindrical defects and relates the defect geometry (residual thickness H, radius r) and the material parameters (Young's modulus E, density ρ and Poisson's number υ) to the LDR frequency f_O.

$$f_0 \approx \frac{1,6H}{r^2}\sqrt{\frac{E}{12\rho(1-\upsilon^2)}} \tag{1}$$

Later, an equivalent solution (Eq. (2)) for quadratic-shaped defects with side length s was found [3]:

$$f_0 \approx \frac{4\pi H}{3s^2}\sqrt{\frac{E}{6\rho(1-\upsilon^2)}} \tag{2}$$

Recent contributions of other groups in the subject demonstrated the benefit of LDR for inspection of delaminations [4], impact damage [5] and kissing bonds [6].

Due to the high efficiency that LDR can provide, a low input power (< 1 W electrical power) is sufficient to activate the defects. This opens up applications with inexpensive excitation sources, e.g. simple piezo disc transducers, or very flexible solutions like vacuum attached piezo shakers.

While using laser scanning vibrometry is the most direct way for visualizing vibration patterns, other useful methods of visualizing local defect resonances exist. Interferometric techniques, for instance shearography and thermal techniques like vibrothermography [7] can provide much faster and in particular more cost-efficient imaging approaches.

1.2. Vibrothermography using LDR

Vibrothermography, also known as acoustic thermography [8], ultrasound excited thermography [9], sonic IR [10] or thermosonics

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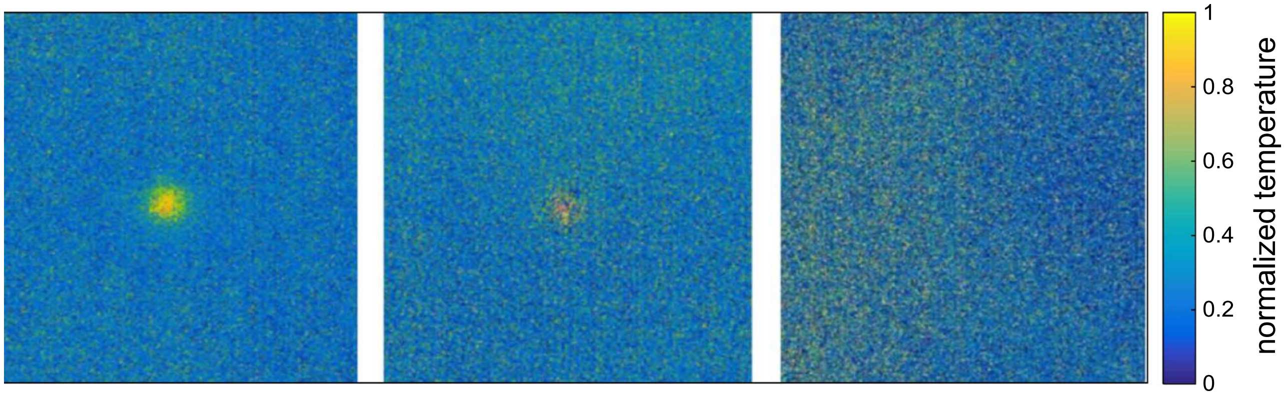

Fig. 1. LDR-thermography results for a CFRP with impact damage at center position.

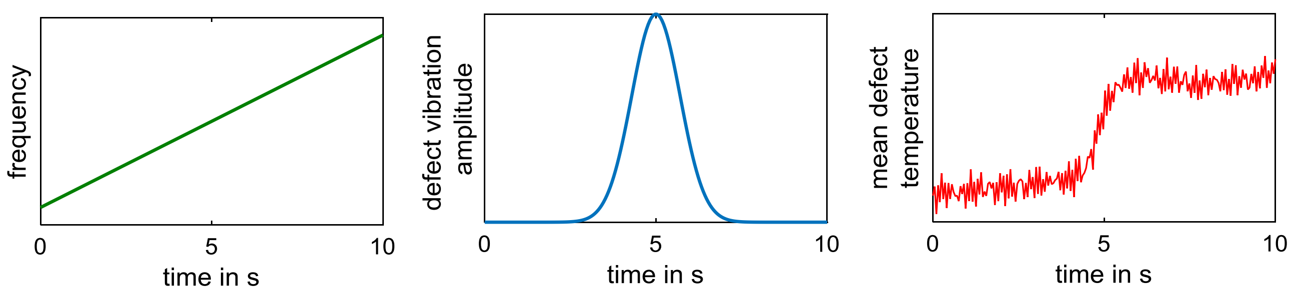

Fig. 2. Sweep signal (left) and corresponding acoustic (center) and thermal (right) defect responses.

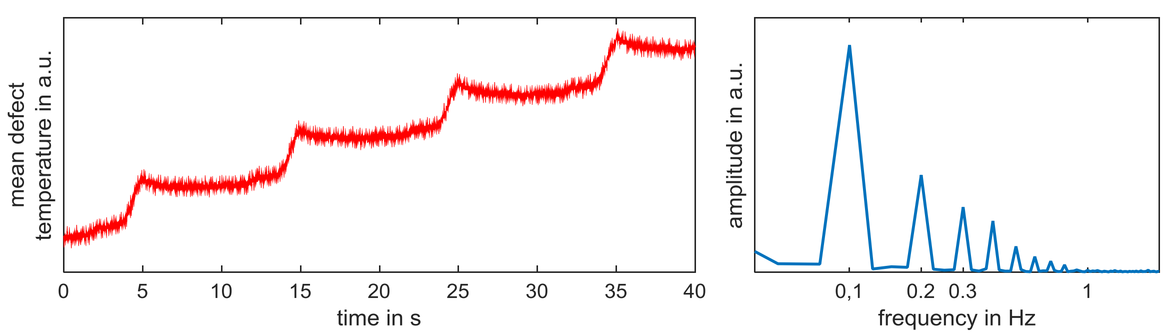

Fig. 3. Periodic temperature signal due to repeated defect activation (left) and corresponding Fourier analysis (right).

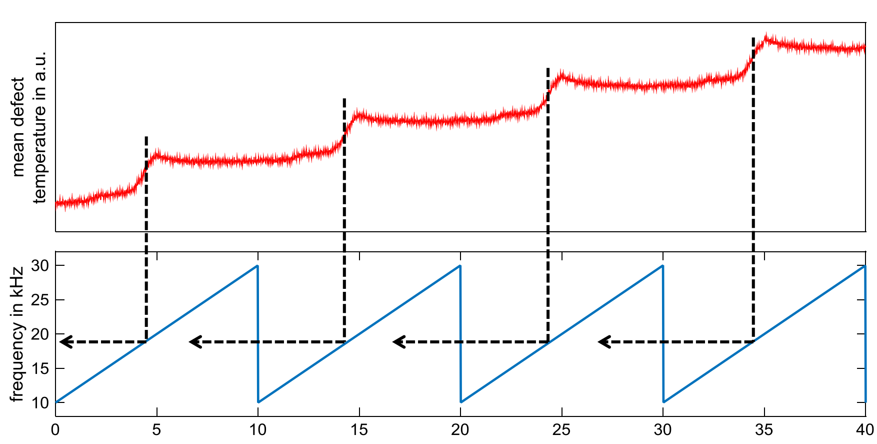

Fig. 4. Periodic temperature signal due to repeated defect activation (top) and corresponding excitation signal (bottom).