Feasibility of a Nonlinear Resonant Ultrasound Spectroscopy (NRUS) for Diagnosis of Micro-cracks

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1. Introduction

Micro-cracks caused by materials degradation and damage will affect the resonance spectrum of a sample only very slightly and be masked by the resolution of the frequency spectrum when we use a standard linear Resonance Ultrasound Spectroscopy (RUS) analysis. However, the damage produces a nonlinear stress-strain relationship and the nonlinearity can be measured by increasing excitation amplitudes. The more damage, the larger is the level of nonlinearity, and it can be used to for diagnosis of micro-cracks.

Non-linear RUS or NRUS can investigate and analyze the amplitude dependence of certain resonance frequencies and uses this information to quantify the degree of nonlinearity and diagnose the micro-cracks.

Undamaged or intact materials show essentially linear in their resonant response. The same material, however, becomes nonlinear when damaged, manifested by amplitude dependent resonance frequency shifts and normalized resonance patterns. The amount of non-linearity is highly correlated to the damaged state of the material.

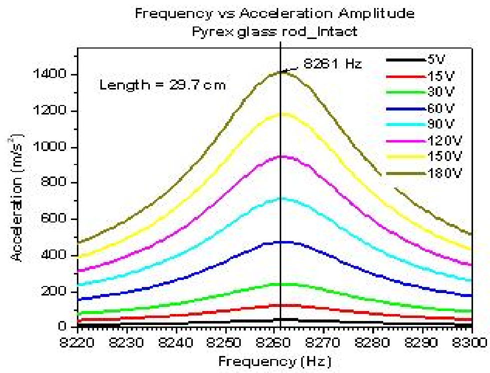
In this study a feasibility of NRUS for a diagnosis of micro-cracks are investigated. A shift of resonance frequency as a function of driving voltage or strain is chosen as a nonlinear parameter to correlate the micro-cracks or damage. In addition we found a normalized resonance pattern also reflects the nonlinearity and the normalized patterns of intact sample and cracked sample were compared and analyzed.

2. Methods and Results

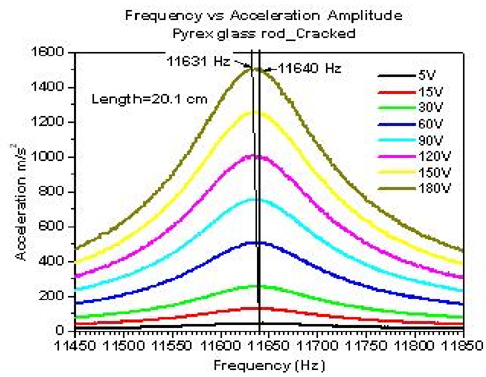
2.1 Resonance Frequency Shift

A Pyrex glass material is known as a linear material and thus used as a standard for calibrating the nonlinearity measurement system. An intact Pyrex bar was chosen for checking the accuracy of our measurement system. Fig. 1(a) shows a typical resonance pattern of linear material. There is no frequency shift and it means linear response.

A cracked Pyrex glass was fabricated by a thermal shock, such as heated up to 400°C and cooled in furnace. Fig. 1(b) shows a shift of resonance frequencies with increasing driving voltage, which means nonlinear response.



(a)



(b)

Fig. 1 Resonance frequency versus acceleration amplitude for a Pyrex Glass; (a) Intact and (b) Cracked.

2.2 Normalized resonance pattern

Another nonlinear parameter in NRUS is the normalized resonance pattern. If the sample is linear, the normalized resonance pattern is exactly same even the driving amplitude varies. As the driving voltage increases, there is almost no change in normalized resonance pattern shown in Fig. 2.

Fig. 3 shows a result from a cracked Compact Tension (CT) specimen. It can be seen the normalized resonance patterns are reduced as the driving voltage increases.

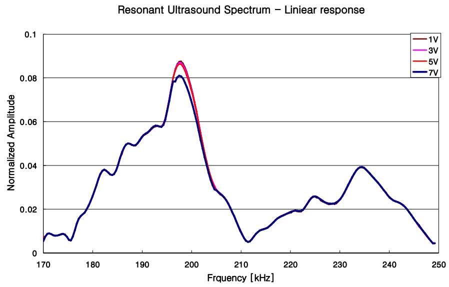


Fig. 2 Normalized resonance frequency pattern of an intact sample (composite) shows a linear response.

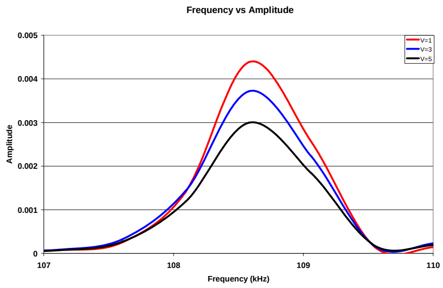


Fig. 3 Normalized Resonance frequency pattern of a cracked sample (CT specimen) shows a nonlinear response.

3. Conclusions

The feasibility of the NRUS technique to diagnose the micro-cracks or damage was investigated. Two nonlinear parameters, shift of resonance frequency and normalized resonance pattern are chosen to distinguish the intact and cracked specimen. These nonlinear parameters can be a potential tool for the detection of micro-cracks or damage of a material. More study is required for a quantitative analysis of materials degradation and damage.

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