1.3.51. NONLINEAR ULTRASONIC NDT FOR EARLY DEFECT RECOGNITION AND IMAGING

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A rapid growth of new high-tech materials used in safety critical applications imposes strict requirements to manufacturing reliability, quality assurance of industrial products and health monitoring of existing components. This evokes development of a new generation of NDT methodologies which provide much greater sensitivity to material structure, incipient micro-defects and progressive damage.

Conventional ultrasonic NDT equipment is normally a mono-frequency instrument which makes use of the amplitude and phase variations of the input signal due to its scattering by defects. One can bear with such inadequate amount of information as long as the wave-defect interaction is believed to be linear. The nonlinear approach to NDT (NNDT) is concerned with nonlinear response of defects, which is related to the frequency changes of the input signal. These spectral changes are caused by anomalously high nonlinearity of micro- and macro-scale defects. The intact parts of the material outside the defect vibrate linearly, i.e. with no frequency variation in the output spectrum. Thus, in NNDT, a small cracked defect (transparent in a linear ultrasonic NDT) behaves as an ***active*** radiation source of new frequency components rather than a ***passive*** scatterer in conventional ultrasonic testing. This makes the NNDT a unique defect-selective instrument for localising and imaging of nonlinear flaws. The latter include a numerous class of contact defects, scaled from dislocations (nano-scale) to fatigue (micro-) cracks and macro-debonds in joints. Since the micro-contact (nonlinear) defects are only the forerunners of further major damage, the NNDT is thus capable of early recognition of material degradation and "predicting" the oncoming fracture.

In the present paper, the nonlinear spectra generated by planar defects (delaminations, cracks, impacts, etc.) are analysed and the results of NNDT obtained by using the methodologies of nonlinear laser vibrometry (NLV) and nonlinear air-coupled emission (NACE) are reviewed. The NLV uses a sensitive scanning laser interferometer for detecting nonlinear vibrations of defects. The excitation system includes piezo-stack transducers operating at 20 and 40 kHz. After a 2D-scan and FFT of the signal received, the C-scan images of the sample area are obtained for any spectral line within the frequency bandwidth of 1 MHz.

Unlike its optical counterpart, which analyzes the light ***reflected*** from the specimen, the NACE-NDT relies on airborne nonlinear acoustic ***radiation*** from the defects. Direct optical measurements proved that such nonlinear radiation is emitted by the defects only and exhibits particular directivity patterns. The high-frequency (300 – 400 kHz) air-coupled ultrasonic transducers are used for scanning the specimen driven by low-frequency (from 20 to 40 kHz) flexural waves. Within the bandwidth of the transducer, a few higher harmonics (with numbers in the range of 10 – 20) are received and applied for nonlinear defect imaging. The experiments show that the NACE operates well in various constructional materials (wood, concrete, metals) with raw surfaces and rugged defects in components.

A number of case studies will be presented to demonstrate applicability of both the NACE and NLV for NNDE and defect-selective imaging in various materials. Particularly successful examples include hi-tech and constructional materials: intact and damaged wood, impact damage and delaminations in fibre-reinforced plastics, fatigue micro-cracking in metals, and delaminations in fibre-reinforced metal laminates. In summary, the results reported prove that NNDT is a highly prospective approach for quality assessment of materials and components applicable in automotive, aviation, and construction industries.