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A signal processing approach for enhanced Acoustic Emission data analysis in high activity systems: Application to organic matrix composites

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ABSTRACT

Structural elements made of Organic Matrix Composites (OMC) under complex loading may suffer from high Acoustic Emission (AE) activity caused by the emergence of different emission sources at high rates with high noise level, which finally engender continuous emissions. The detection of hits in this situation becomes a challenge particularly during fatigue tests. This work suggests an approach based on the Discrete Wavelet Transform (DWT) denoising applied on signal segments. A particular attention is paid to the adjustment of the denoising parameters based on pencil lead breaks and their influence on the quality of the denoised AE signals. The validation of the proposed approach is performed on a ring-shaped Carbon Fiber Reinforced Plastics (CFRP) under in-service-like conditions involving continuous emissions with superimposed damage-related transients. It is demonstrated that errors in hit detection are greatly reduced leading to a better identification of the natural damage scenario based on AE signals.

1. Introduction

Carbon Fiber Reinforced Plastics (CFRP) materials are increasingly used in aeronautical and automotive industries as well as in civil engineering thanks to their high material properties [1–3]. Since the integrity of CFRP structures needs to be regularly assessed, the Acoustic Emission (AE) technique is widely used to detect and localize eventual damage [4–6]. AE is a non-destructive method able to ensure in situ monitoring of the structure through a network of distributed sensors and can be used to detect damage at a very early stage well before the structure becomes completely failed [8]. When the structure is subjected to mechanical, thermal or chemical solicitations, a stress field is generated in the material. As a consequence of the repetition of these solicitations, the material degrades. The appearance of defects leads to the creation of elastic ultrasonic waves that propagate through the material. This wave propagation involves surface vibrations, which are measurable using appropriate sensors. AE consists hence in a transient elastic energy release in materials when microstructural changes occur. It is dependent on some basic deformation and damage mechanisms. In CFRP composites, major damage mechanisms are delamination, matrix cracking, debonding, fiber cracking, and fiber pull-out [9].

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Three types of AE transients can be distinguished: bursts, continuous and mixed [10,11]. Bursts are generated by defects according to the damage mechanisms and have shorter durations than the other types of transients. Continuous AE transients are created when multiple signals emitted from different emission sources overlap in such a way that the amplitude does not fall below the threshold level. The original transients are often hardly recovered and assigned to their emission sources. The background noise and rubbing in the structure are the main sources of continuous emission. Relevant AE information might be buried by noise preventing the identification of particular damage. Mixed AE transients combine bursts and continuous signals. They can be provoked by damage growth and accumulation and are often superimposed with ambient noise and rubbing [12,13]. This latter type of AE transients is frequently encountered in CFRP structures under complex loading, where the material can be subjected to various solicitations simultaneously (multi-axial stresses, frictions between the clamping jaws and the specimen, etc.) [14]. A high AE activity can be encountered hence, especially when the material is solicited at a high loading rate as well as when its geometry is complex. On one hand, a high loading rate is produced particularly when the cycling frequency is high. Some experimental tests have demonstrated that the AE-hit-rate increases not only with the total number of load cycles but also with the cycling frequency [15]. For highest rates, transients emitted from different emission sources can be superimposed. On the other hand, the inhomogeneity of such a material (fibers, matrices, multiple plies, etc.) engenders anisotropy in the wave velocities. The wave reflections and attenuation (dispersion, geometric spreading, etc.) are also added to the complexity. Complications include steering of the direction of the group velocity caused by the anisotropy of the material, wave attenuation due to damping by the matrix and wave scattering engendered by the fibers [16].

Under in-service conditions, the background noise is sometimes so important that it cannot be neglected. Several sources of perturbation can be the cause. In this study, the noise generated by the hydraulic system of mechanical testing machines is assimilated to a source of perturbation under real operating conditions. The hydraulic fluid is increasingly hot in such machines when the duration of test is long. Irregular flow characteristics and pressure waves propagate through the fluid. A lot of *fluidborne noise* can be so generated leading to force fluctuations. These result in a vibration, known as *structureborne noise*, transmitted through the structure [17]. The AE signals can be affected by this noise when it hides them partially or, in many cases, completely. When the level of noise is permanently exceeding the AE detection threshold, which is the case in continuous emission, the AE system is obliged to terminate the hit after a predefined maximum duration. This latter is configured in the AE system in order to avoid recording long signals. As the threshold is permanently exceeded in such a situation, the AE signal is entirely recorded without a correct hit separation. The consequent AE features can be so affected and the footprint of the noise is not negligible. Most of the commercial parameter-based AE systems employ the conventional threshold-based technique for hits' detection and determination. The AE features are calculated without an efficient consideration of noise variations that can mislead the interpretation of real AE events happening in the material. The AE systems also employ predefined band-pass filters in order to avoid the impact of external perturbations. However, if the noise is generated at frequencies that are comprised within the frequency band of the filter, it cannot be suppressed. Thus, the conventional threshold-based technique could not be suitable when dealing with continuous emission, without a further signal processing.

The approach proposed in this study is based on denoising the recorded AE signals prior to the hits' determination. The Discrete Wavelet Transform (DWT) is one of the powerful methods that has been widely employed for signal denoising, which has been useful for improving the signal-to-noise ratio much better than using signal filtering, as well as for signal processing to detect multiple defect signatures [18–20]. The DWT is based on the Wavelet Transform (WT) theory [21,22], which provides relevant information about non-stationary signals in the time-frequency domain. The WT has been used in many studies related to the Structural Health Monitoring (SHM) field [23–28]. Some other studies have reported on the use of the WT on AE signals for a denoising purpose [29–32].

This work proposes a signal processing approach for the purpose of conditioning AE signals issued from continuous emission caused by ambient noise and high AE-hit-rate. The efficiency of the proposed approach is evaluated on experimental AE signals obtained from PLBs performed on CFRP specimens in a noisy environment with different levels, and from

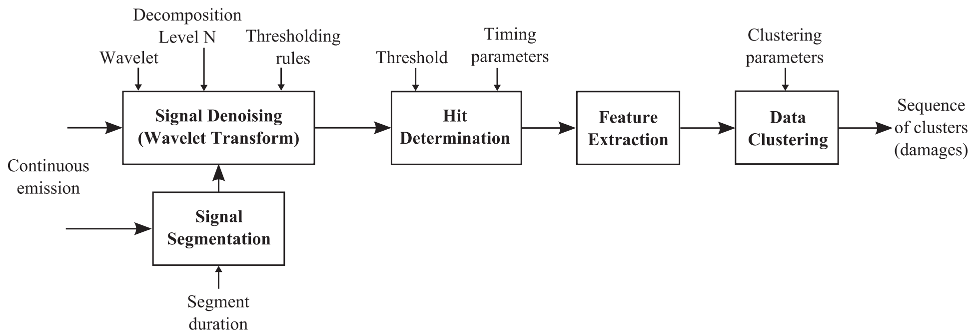

Fig. 1. Principle of the proposed AE signal processing approach.