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Traceability of Acoustic Emission measurements for a proposed calibration method – Classification of characteristics and identification using signal analysis

James Griffin

University of Chile, Beauchef 850, Torre Central, Santiago, Chile

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ABSTRACT

When using Acoustic Emission (AE) technologies, tensile, compressive and shear stress/strain tests can provide a detector for material deformation and dislocations. In this paper improvements are made to standardise calibration techniques for AE against known metrics such as force. AE signatures were evaluated from various calibration energy sources based on the energy from the first harmonic (dominant energy band) [1,2]. The effects of AE against its calibration identity are investigated: where signals are correlated to the average energy and distance of the detected phenomena. In addition, extra tests are investigated in terms of the tensile tests and single grit tests characterising different materials. Necessary translations to the time–frequency domain were necessary when segregating salient features between different material properties. Continuing this work the obtained AE is summarised and evaluated by a Neural Network (NN) regression classification technique which identifies how far the malformation has progressed (in terms of energy/force) during material transformation. Both genetic-fuzzy clustering and tree rule based classifier techniques were used as the second and third classification techniques respectively to verify the NN output giving a weighted three classifier system. The work discussed in this paper looks at both distance and force relationships for various prolonged Acoustic Emission stresses. Later such analysis was realised with different classifier models and finally implemented into the Simulink simulations. Further investigations were made into classifier models for different material interactions in terms of force and distance which add further dimension to this work with different materials based simulation realisations.

Within the statistical analysis section there are two varying prolonged stress tests which together offer the mechanical calibration system (automated solenoid and pencil break calibration system). Taking such a mechanical system with the real-time simulations gives a fully automated accurate AE calibration system to force and distance measurement phenomena.

1. Introduction

When machining aerospace alloys, there are a number of signal extraction technologies that can be used to identify the onset of malfunction which promotes efficient machining for the duration of manufacture. A key point to note here is the use of a calibration method that is both recorded and referenced to previous energy patterns. To ensure this process, information is recorded and interpreted and if a condition of concern is identified this must be evaluated in terms of its energy level and if further diagnosed as a concern, must then be acted on [3]. In contrast, AE is less established in industry

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than other signals such as force, accelerations, strain, temperature, torque and power which are all internationally recognised standards where AE is not. This is difficult to do due to the nature of extraction where AE is sensitive to minute material dislocations and such measurements can differ significantly due to daily environmental changes such a temperature, air pressure and humidity to name a few. Such differences attribute to different signal time of flights, change of wave reflections, differences in material mediums and lastly, the difference in the process of calibration. The method presented in this paper ensures a correlation from known standardised phenomena to the less verified phenomena of AE.

Other sensors such as force are very useful for extracting workpiece deflection and even stiffness characteristics. Moreover, AE and force sensors look at similar conditions within the machining environment with importance being placed on the correct interpretation of the signal where different facets are extracted due to the different sampling frequencies used for the different sensing technologies. This paper will discuss all the AE signal representations against known phenomena.

Distance and force correlate very well for AE calibration when analysing the rich summarised extracted time signal; however to gain more useful information in terms of the material differences, a high bandwidth of AE frequency response needs to be identified and recognised. With rich information in the form of frequency band intensity it is possible to separate different material interactions exerting the same force at the same distance from the AE sensor(s). The method presented in terms of signal processing for preparation to the classifier uses a rich summary extraction technique to segregate time extracted signals in the form of the 5 highest peaks and the 5 lowest troughs and their associated time steps to the next proceeding zero point in time. This summary data technique is carried out for every 100 points of extracted data to give a 20 summary data points representation (5:1 compression ratio) which gives a rich summary of data (5 max, 5 min and 5 related times from the respective min–max points to the next zero point in time). This gives useful information in terms of both intensity and intensity to distance (hence the higher the frequency/amplitude components the closer the phenomenon). Such a technique is considered powerful and computationally affordable. If however there is more than one material being calibrated against then a more powerful technique is required which is more computationally demanding. Such a technique is one that translates the time to the time–frequency representations (such as Short-time Fourier transforms (STFT)) and segregates the different material interactions made by prolonged stress when applied to different materials. For a generic classifier system correlating force and distance of different materials extra frequency components from the STFT (5 max frequency peaks for that 100 points of time data) is added to the rich summary data information giving an even richer representation. The 20 points windowed summarised data is taken across every 100 points of the raw extracted AE signal and for the duration of average signal phenomena (1000 points of raw extracted AE signal).

The last section of the paper investigates intelligent models with Neural Network (NN) representations, Fuzzy clustering and tree rules based classifiers providing verified model predictions for distance and force when an AE source is emitted from prolonged stress. Further work in distinguishing signal phenomena for different materials is also discussed taking the time series summary representation further.

The main investigation objectives of this paper are

- Characterise the force and distance phenomenon in horizontal SG scratch tests.
- Characterise force and distance phenomenon using a rich summary signal pre/processing technique.
- Characterise AE to force and distance phenomenon for pencil break calibration tests.
- Characterise AE to force phenomenon for tensile tests.
- Characterise AE to force phenomenon for different material tests.
- Characterise and analyse AE in terms of statistical measurements for possible calibration technique: SG, pencil break and tensile tests.
- Characterise and analyse AE in terms of statistical measurements for possible calibration technique: varying intensities for pencil break and solenoid prolonged stress measurements.
- Verify signals with Dual AE sensors set equal distances apart and from sensor delay determine the position of the scratch interaction.
- Classify force and distance data using NN technique.
- Verify the classification process using training, test and verification data using fuzzy clustering and tree rule based classifiers.
- Produce AE to force and distance simulation displaying changing energy patterns as the prolonged stress changes in intensity (all the above objectives displayed within the proposed simulation).
- Produce AE to material distinction simulation displaying changing energy patterns from the same prolonged stress against different material mediums.

The remainder of this paper is organised as follows: Acoustic Emission technology (Section 2), Experimental Setup for AE calibration tests (Section 3), Acoustic Emission Analysis and Results (Section 4), Classifier Technologies (Section 5), Classifier Results (Section 6), AE Calibration Model Simulations (Section 7), Discussion of Results (Section 8) and Conclusions (Section 9).

2. Acoustic Emission technology

AE has been used for materials research in monitoring stresses from AE events emitted from crack initiation, structural defects, measurements, and other material anomalies. From such work it was found that most materials emit sounds or stress