# A Parameter Correction Technique (PCT) for Acoustic Emission Characterisation in Large-Scale Composites

Safaa Kh. AL-JUMAILI [1,2], Mark EATON [1], Karen HOLFORD [1], Rhys PULLIN [1]
[1] Cardiff School of Engineering, Queen's buildings, The Parade, Cardiff, CF24 3AA, UK
[2] University of Basrah, Basrah, Iraq
E-mail addresses: Al-JumailiSK@cf.ac.uk (Safaa Kh. Al-Jumaili), Holford@cf.ac.uk (K.M. Holford), PullinR@cf.ac.uk (R. Pullin), EatonM@cf.ac.uk (Mark J. Eaton).

**Abstract.** Acoustic emission (AE) has been extensively used for over 40 years for non-destructive evaluation of damage in different types of materials and structures. Damage identification is considered as one of many attractive attributes of this technique. Most studies in this field have been conducted on small-scale specimens by analysing the AE parameters recorded using different commercial AE acquisition systems directly. However, these AE parameters are affected by attenuation, superposition, material properties and complex geometry which can lead to incorrect input data in the analysis process, thus making accurate characterisation challenging. Furthermore, using AE for the Structure Health Monitoring (SHM) is highly dependent on the recorded parameter values for decision making on the integrity of the structure.

This paper describes a novel solution to enable AE parameters to be "corrected" to account for the material properties and the geometry of the structure. The ''Parameter Correction Technique (PCT)'' utilises an artificial source; recording the relationship between the signal parameters and varying source amplitude from a number of locations, to create a multi-layer map to correct the recorded parameter value. A five-step description of the process is provided and practical results from an initial trial are presented. Initial trial results demonstrate a considerable improvement over the conventional parameters.

Various artificial sources were used to assess the performance of the Parameter Correction Technique in a composite panel. The technique is demonstrated on a single parameter analysis (namely amplitude) and the correlation plot. In order to demonstrate the advantage of the PCT, the traditional AE parameters are presented side-by-side for comparison, which reveals a substantial improvement in parameter value accuracy. The effects of attenuation, anisotropy etc. have been eliminated using the new method. Moreover, it is proven that AE signal propagation path seriously affects the recorded AE parameters and cannot be ignored. Thus, the PCT is an effective technique that may be used to overcome signal propagation effects and correct the recorded qualitative parameters to provide a better discrimination of different sources types in composite materials.

## Introduction

Acoustic emission (AE) is a non-destructive testing technique which has been widely used in research applications for the detection of micro failures in a wide variety of materials [1]. The origin of the AE in materials is that when a failure mechanism is activated, part of the total strain energy is dissipated as mechanical stress waves, which are spread concentrically around the place of origin. The energy released in this way can be detected with suitable sensors: the recorded mechanical information from the material is then converted into an electrical signal [2]. During the last two decades, composite materials have found use in numerous industrial applications and nowadays, reinforced composite structures are widely used in large-scale and safety critical structures for infrastructure and transport, (aerospace, energy and marine). For large-scale metal or composite structures, acoustic emission (AE) has great potential for use in structural health monitoring (SHM), providing continuous and global monitoring of the structure, the ability to locate the AE source position within the structure and providing information about the damage mechanisms from the received signals.

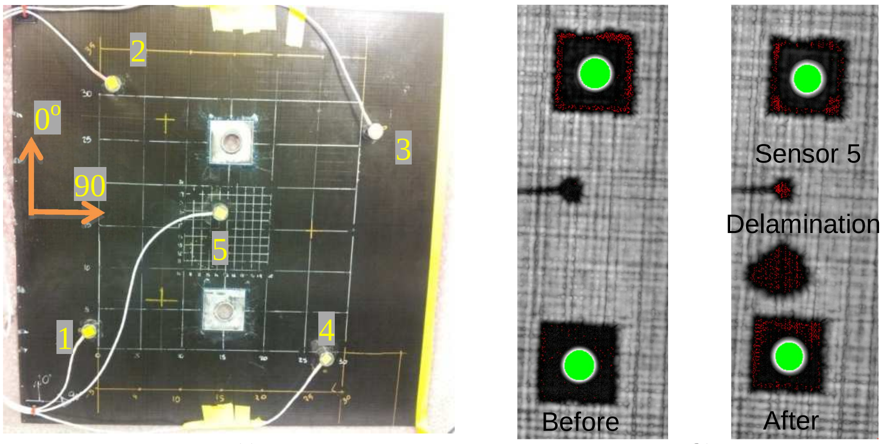
To date most studies carried out for identification damage mechanisms in composite materials under different loading regimes have been based on conventional AE analysis using the recorded AE signal features directly from the acquisition system. Until now the association of each AE signature to a specific failure type is considered to be a non-trivial task in large-scale composite materials components. Due to the complex nature of the structure of a composite material the wave propagation and scattering phenomenon is highly complex. Also, the complexity increases as a result of signal transition interruption due to the presence of obstacles such as cracks, holes and thickness changes, in the propagation path. In addition, the AE signal energy degradation makes the collection of all the AE activity using one sensor difficult. On the other hand, the use of data collected from multiple sensors is highly problematic in terms of achieving accurate analysis due to the different transfer functions of each sensor.

This paper proposes a solution which will eliminate the effects of attenuation, anisotropy etc. on the recorded AE signals. A novel AE parameter correction methodology known as “Parameter Correction Technique (PCT)” is presented, which is applicable to two-dimensional plate-like structures. It is applied in order to correct the recorded AE parameters from artificial sources which are generated at different locations on a carbon fibre composite panel specimen. This technique has the ability to use the data recorded by all the sensors in an array to correct each signal’s parameters, improving reliability and confidence. Because of the novelty of this approach and the lack of relative studies in the field of AE parameter correction; only a comparison with the traditional parameters was made to assess the technique performance. The four fundamental parameters, amplitude, duration, count and energy were corrected in this work with high accuracy. In the presented analysis, events are located accurately using the Delta T technique. Originally developed for complex geometry metallic structures [3], the technique has also been shown to perform very well in anisotropic materials such as composites [4].

## 2. Experimental Procedure

### *2.1 Test specimen*

The experiments were carried out on a carbon fibre composite panel manufactured from Hexcel Corporation material code is M21/35%/UD268/T800S. The final product is a layered structure specimen with 8 ply of uni-directional pre-preg using a $((0, 90)_2)_s$ with dimensions of 500 x 500mm with nominal thickness of 2mm. During the layup process an artificial crack was introduced in the centre of the specimen by cutting the fibre in 0$^o$ direction using a fresh razor blade to initiate an artificial matrix crack of 2.5mm length. Four aluminium plates with 5 x 50 x 50mm dimensions were glued on both sides of the panel using resin and a 20mm diameter hole drilled as shown in Figure 1a. Local delamination was produced using a low velocity impact of polished hemispherical tup with a 20mm diameter with different energy levels from 5 to 14 J on the specimen surface. Figure 1b shows the C-scan images of the specimen before and after impact with the delamination area.




(a) (b)

**Fig. 1.** (a) Test specimen configuration (b) C-scan images before and after impact.

*2.2 Acoustic emission:*

AE activity was recorded using a Vallen acquisition system at a sample rate of 5 MHz. with five PAC WD wideband sensors of bandwidth 100-1000 kHz and a resonant frequency at 650 kHz as presented in Figure 1a. All sensors were pre-amplified using the Vallen AEP3 of 34 dB gain and a threshold level of 44.9 dB was set. The threshold level was selected to eliminate background noise. Silicon adhesive (595 Loctite) was used to provide both acoustic couplant and mechanical fixture between the specimen and the sensors. Installed sensor sensitivity was evaluated using a Hsu-Nielson (H-N) source [5]. Artificial sources were generated from a PAC wave generator and the signal transferred using a conical transducer. The multi purposes grease was used as a couplant to provide good contact between the conical transducer and the specimen surface. Figure 1a demonstrates the Delta T location grids. A 50mm grid resolution and with 10mm resolution near to the artificial crack was applied to the central area of interested of 300 x 300mm. The Delta T location maps was constructed before the test by record data from five pencil lead breaks, H-N sources, at each grid point.

## 3. Parameter Correction Technique (PCT) methodology

This technique utilises an artificial source, recording the relationship between the acquired signal parameters and varying source amplitude from a number of locations, to create a PCT multi-layer map for each sensor. This method does not require knowledge of the sensor location or wave velocity. A five-step description of the technique is provided.

- *Determine area of interest:* The PCT method can offer complete coverage of a structures. However PCT can be time consuming but it can also be applied to a small or critical component.

- *Map system Construction:* A grid is constructed on the area of interest within which AE events will be located. It is important that source position and not the sensor should be referenced to the grid. Placing the sensors within the grid is unnecessary and does not affect the final result.
- *Apply artificial sources to obtain the PCT data set: an* artificial source is generated at each node of the grid with different amplitudes (input voltage) and recorded at each sensor. At each amplitude the source is repeated several times and an average result of the parameter values is used to reduce the error. Data between nodes and for missing nodes as a result of holes for example can be interpolated from the other surrounding nodes. So, for each sensor, a distribution contour will define each parameter value within the grid, this is completed for each different input voltage.
- *Calculate PCT maps:* For each sensor, the parameter contours are arranged in ascending order depending on the source amplitude value. This allows construction of a multi-layer matrix (PCT map). At each location within the grid, the relationship between parameter value and the artificial source amplitude value is calculated.
- *Real AE data parameters re-calculation:* For each sensor, any previous, current or future located AE data received can then be overlaid on the relationships, and its source amplitude can be identified. Interpolation and extrapolation are utilised to obtain these values. The average from all sensors that record the same event is used to present the most accurate value.

*3.1 Initial PCT practical calculations:*

In this work, the training data for the PCT mapping was collected from an area of 300 x 300mm, identical to the Delta T map area. All dimensions will be referred to the left hand bottom corner of the Delta T map as the origin. A grid density of 50mm was used, creating 47 nodes on the PCT mapping area as shown in Figure 2a. Two nodes were in accessible due to their location within the tab holes (Figure 1a). The location of nodes next to the sensors was shifted by approximately 10 to 20mm to be able to use the conical transducer. An artificial pulse (the excitation pulse is rectangular shape of 10 µs width) was used at each node. Pulse amplitude started from 10 V to 160 V with 5 V increments. At each increment the pulse was repeated 5 times to provide an average and avoid any erroneous results. Real-time recording of AE signal parameters using the five sensors was obtained. Data at each node was used to interpolate across the entire grid.

Figure 2b shows the traditional amplitude values recorded by sensor 1 (Figure 1a) within the grid from a 160 V source amplitude. It can clearly be seen that the recorded parameter values vary strongly with the source location and its clear how the propagation distance, propagation direction and geometric properties affect the amplitude. As a result it is difficult to characterise between AE signals of different sources emitted from different locations using the traditional AE signal parameters. The multi-layers matrix of the PCT map is presented in Figure 2c.

It is worth to note that using the parameter distribution contour showed in Figure 2b to correct AE parameters has many limitations, because each damage mechanism generates signals with different levels of energy as well as amplitude. In addition, the final result of correction will depend on the operator decision to choose which sensor data to utilise and the distance from that sensor.

From Figure 2c it is possible to extract the parameter value in any position within the grid at each source voltage. Thus, for each sensor, the relationship between the parameter values and the source voltage at any location can be obtained. Figure 2d shows examples of these relationships between the traditional amplitude, recorded by sensor 1, and the source voltage in three different arbitrary positions. The same process was conducted for the remaining parameters (count, energy and duration).

In this approach parameter values of the located AE events are overlaid on these relationships to identify the source amplitude. Thus the corrected traditional parameter will be referred to the next as the input voltage in volts.

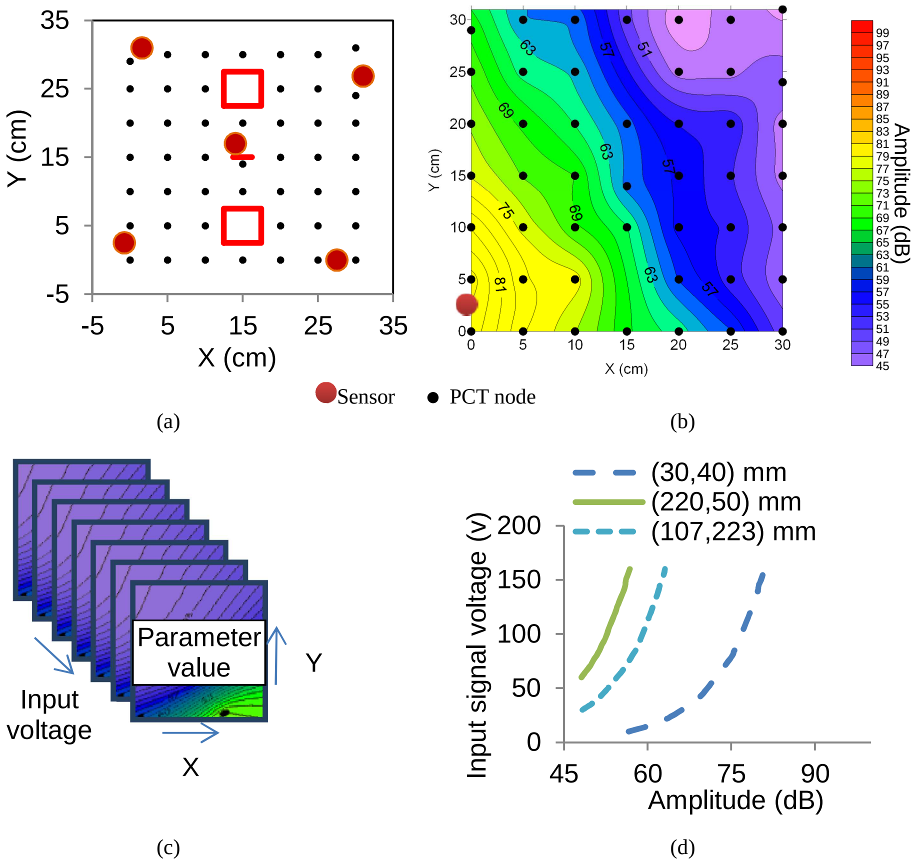



**Fig. 2.** (a) PCT grid (b) traditional amplitude recorded by sensor 1 (c) PCT map structure for one parameter from one sensor (d) traditional amplitude with the source amplitude relationship at different locations.

## 4. Validations Approach

In order to validate and assess the performance of the proposed technique, validation tests were performed using different artificial sources as a repeatable AE sources. Three tests were conducted; firstly using different sources amplitude (Codes 001, 002 and 003). Secondly, use different pulse shape sources (Codes 002 and 007). Thirdly, using different frequencies pulses (Codes 007, 009 and 010) (Further sources codes 004, 005, 006 were investigated but are not reported here). The sources details are listed in Table 1.

Six arbitrary positions were chosen to conduct this investigation and each source was repeated 5 times at each position. The positions will be labelled during the rest of this paper according to the information provided in Table 2.

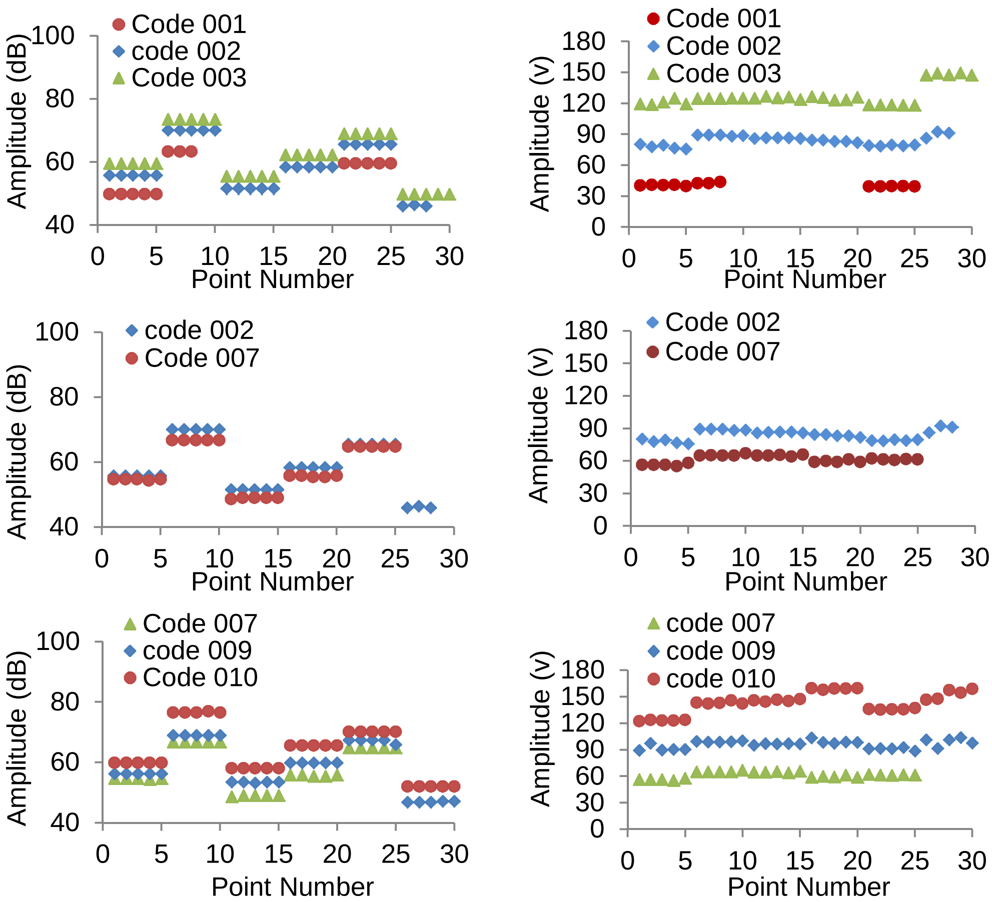
The source position was located using the Delta T technique. The average location error between the actual and calculated locations of all sources was found to be 6.6 mm. A comparison between the traditional parameters of sensor 1 and the PCT result is presented in Figure 3. Only the amplitude comparison is presented here however the same results were achieved for the remaining parameters.

**Table 1.** Artificial sources details

| Source code | 001 | 002 | 003 | 007 | 009 | 010 |
|---|---|---|---|---|---|---|
| Pulse name | Sine wave | Sine wave | Sine wave | Saw tooth | Saw tooth | Saw tooth |
| Wave envelop | Sine curve | Sine curve | Sine curve | Sine curve | Sine curve | Sine curve |
| Frequency ( kHz) | 300 | 300 | 300 | 300 | 200 | 100 |
| Cycle | 1 | 1 | 1 | 1 | 1 | 1 |
| Amplitude (V) | 50 | 100 | 150 | 100 | 100 | 100 |

**Table 2.** The location label and its location on the specimen

| Point number | X (mm) | Y (mm) |
|---|---|---|
| From 1 to 5 | 75 | 275 |
| From 6 to 10 | 75 | 60 |
| From 11 to 15 | 150 | 140 |
| From 16 to 20 | 75 | 175 |
| From 21 to 25 | 0 | 200 |
| From 26 to 30 | 150 | 300 |




(a) Sensor 1 data (b) Prameter Correction Technique (PCT)

**Fig. 3.** Comparison between traditional and corrected amplitude.

As we can see the traditional amplitude was recorded with different value levels (Figure 3a) depending on the source location from the recording sensor. Demonstrating a challenge to use them for discrimination between different source types. While, the corrected amplitude value from all the six locations has a relatively stable level demonstrating that PCT eliminates the propagation effects on the recorded parameters. The fluctuation in the PCT results is related to the source location accuracy.

Furthermore, the ability of the PCT to use all sensor data has an advantage, that no missing AE data, and all the located events can be compared for the final analysis. Up to now, the traditional AE analysis suffers as only one sensor should be used to compare located sources, leading to in most cases missed data. This problem could be significant in large-scale components due to the attenuation. For example, in each position the source Code007 was repeated five times so ideally there are 30 located events. In reality the Delta T locates only 25 events as presented in Figure 3a because some source signals hit less than three sensors, the lowest number required to locate event in 2D [3]. Sensors response of this source is provided in Table 3:

**Table 3.** Sensors response of the source Code007

| Sensor No. | Number of signals hitting the sensor | % of located data |
|---|---|---|
| 1 | 25 | 100 |
| 2 | 25 | 100 |
| 3 | 15 | 60 |
| 4 | 10 | 40 |
| 5 | 25 | 100 |
| The PCT | 25 | 100 |

It can be seen clearly from Table 3 that if the traditional analysis is conducted using sensor 3 or sensor 4 mean 40% and 60% of the located AE activity is lost, respectively.

For the detection and potentially the characterisation of damage, correlation plots are used extensively in classic AE testing. One of the commonly used is the amplitude versus duration plot. It is hoped in an ideal case the plots would group the AE data points based on their mutual similarity.

A comparison between traditional and corrected parameters correlation plots of the three tests was performed and the result is presented in Figure 4. In the traditional parameters plots the different sources singles have random distribution as shown in Figure 4a. On the other hand, the corrected parameters in Figure 4b show significant improvement and each source is separated into a distinct cluster.

## Conclusions

In the present investigation, a new technique was examined using a variety of artificial sources on different locations on the carbon fibre composite specimen. A continual significant improvement in overall performance/efficiency factors was achieved in correcting the traditional parameters value recorded from different amplitudes, waveform and frequency sources.

A comparison with traditional parameters was conducted using single parameter analysis and correlation plots. Results reveal that the traditional parameters are completely misleading if used for damage identification process in large-scale components. This technique has the ability to use all sensors which improves the results accuracy and avoids losing AE data. These findings show great potential for the use of AE monitoring in SHM of large-scale composite structures such as those found in the aircraft industry and in wind turbines.

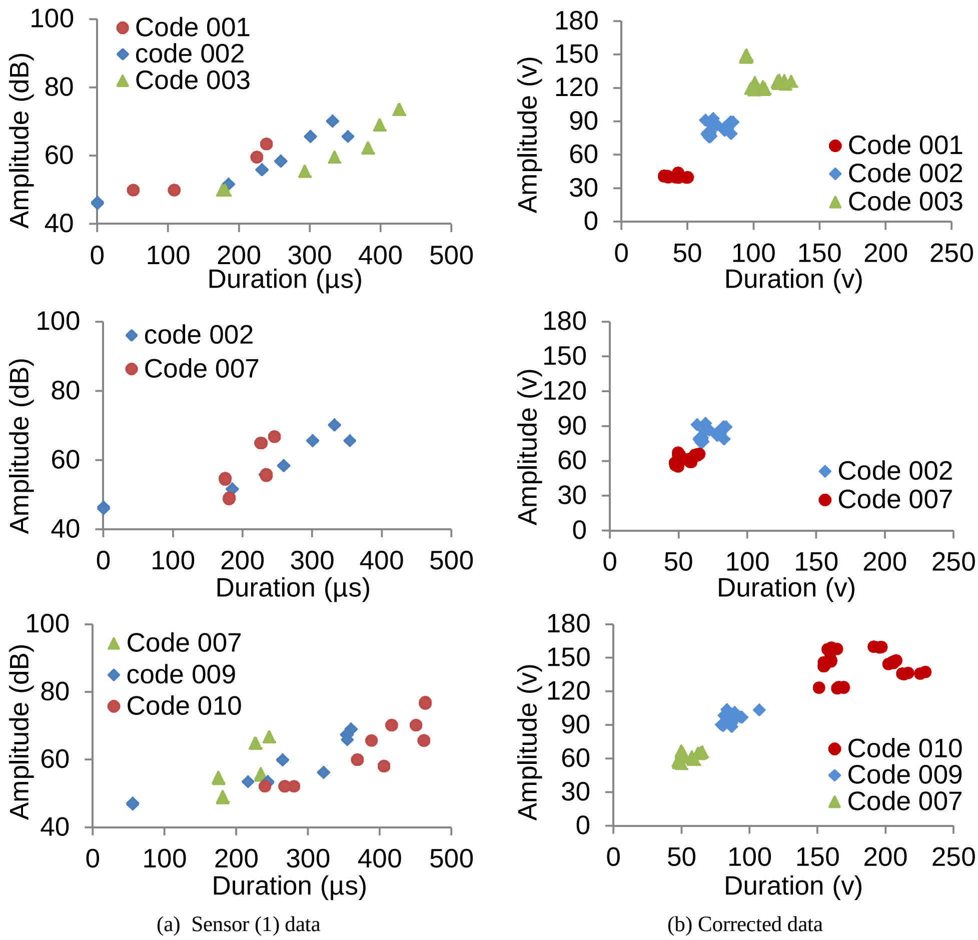



**Fig. 4.** The correlation plots using traditional parameters and the corrected parameters using PCT.

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