FYI

Basics of AE Analysis for Field Testing: Part 1

By Stanley F. Botten

In the field of acoustic emission testing (AE), the response of the sensor to the release of energy due to metals deforming in alloys, used in pressure vessel manufacturing with controlled stress when they reach 60% of the yield stress, is well documented (Dunegan 1971; Pollock 1973; Spanner 1973; CARP 1987; Heiple and Carpenter 1987; Fowler 1992; ASTM 1999).

However, the acoustic emission activity from other sources is not recognized by some practitioners in this field. The author, having conducted thousands of AE tests on different materials, has encountered several factors that influence the amplitude, energy, duration, and rise time of the waveform recorded by the AE sensor. This article explains some of the phenomena and how to better understand their effect on the acoustic emission signature. Both metals and composite materials are discussed.

This article has been divided into two parts. The first part includes a basic description of the method and other important factors to be noted. The second part (to be published in July 2021) will discuss the influence of the various materials used in construction and their effects on the AE data.

Description of AE Method

Acoustic emission is a sudden, transient release of energy that takes place due to material deformation, structural failure, or similar. Acoustic emission is similar to when rock formations crack in natural seismic events. This release is of short duration. The extent or amplitude of the transient release is measured on the Richter scale from 0 to 10, and the major difference between seismic and acoustic emission events is the frequency spectrum. For seismic, it is in the region of 0 to 60 Hz (cycles per second), whereas the frequency spectrum for acoustic emissions is most commonly between 20 and 1000 kHz.

If an analysis of the frequency spectrum for the seismic event is performed, it is noted that the frequency is broadband. The seismic industry is required to detect earthquake events over long distances. Physics prove that the greater the distance, the greater the attenuation (absorption) of the energy that takes place at higher frequencies; hence the use of low-frequency sensors. AE, as it is commonly called, is used in industrial applications, which makes it impossible to distinguish the different noise sources at these low frequencies. However, in AE the distances between the sensors rarely exceeds 30 m, so the use of high-frequency sensors is an advantage. By using high-frequency sensors and removing the low-frequency unwanted or nonrelevant noise sources with bandpass filters (first utilized in the early 1960s), the acoustic emission signals can be detected while in the operating environment.

Computer Analysis

High-speed computers and improved software have made it possible to closely examine the acoustic emission waveforms and to perform signature evaluation with greater accuracy.

Since the inception of AE in 1968, there have been tremendous advancements in computer technology and software, which in turn has influenced the use of acoustic emission signature recognition techniques and data collection speeds. For example, because the data capture and resolution in 1986 took approximately 100 milliseconds (ms), it was difficult to record all the transients. By comparison, in 2001 data could be collected at a rate of 250 nanoseconds (ns) and gigabytes of data could be stored instead of only 120 MB. This vastly improved the technology and reliability of this NDT method.

Figures 1 and 2 depict a typical AE setup with the corresponding signal data reported by AE analysis software.

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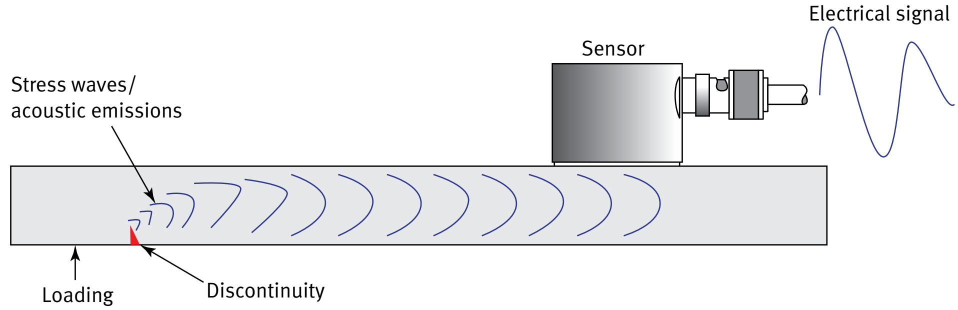

Figure 1. Acoustic emission stress waves.

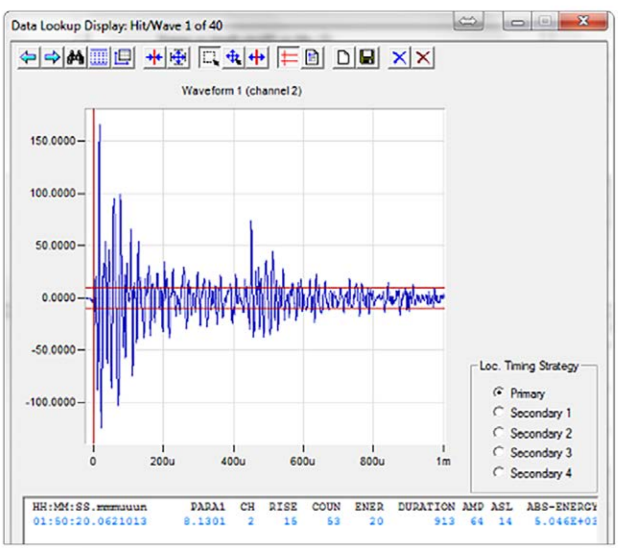

Figure 2. Display of a typical acoustic emission waveform.

The total purpose of this article is to look at the key features of the waveform along with the major factors that must be considered when interpreting the AE signal data.

Measurement of the Acoustic Emission Signal

The common practice in AE is to quantify and record the digitized waveform of the acoustic emission signal, or "hit." To do this, the analog response from the AE sensor is recorded with the following features of the waveform (see Figure 3):

- Amplitude: the maximum voltage amplified through a preamplifier. The range is 30 to 100 dB AE.
- Rise time: the time in microseconds (μs) from the first threshold crossing to the peak amplitude.
- Duration: the duration of the hit in μs from the first threshold crossing to the last crossing.
- Energy: the measured area under the ring down height response curve (labeled "D" in Figure 3); it uses the formula $\int_0^t |v| dt$, also referred to as *marse* or *signal* (where v = voltage and dt = Delta time).
- Strength (most data-collecting software uses the term "energy").
- Counts: the number of threshold crossings. (This is related to frequency and is not normally used by the author in evaluation.) The higher the frequency of the AE sensor, the greater the count for the same hit recorded.
- Average signal level (ASL): the mean or average signal level measured in dB AE, used to quantify leaks and mechanical rubbing.
- Threshold: the setting used to eliminate unwanted noise levels, similar to the reject level used in ultrasonic testing (UT). The higher the threshold, the lower the detection level. In normal AE, this is set at 40 dB for data collection and raised to 50 dB for evaluation purposes.

Effects of Materials on the Acoustic Emission Signature

When using standard AE data collection techniques, it is important to know as much as possible about both the history of the structure and the material used in its construction. The material properties affect the acoustic emission signature in a few ways, and those properties can be modified by age and load history.

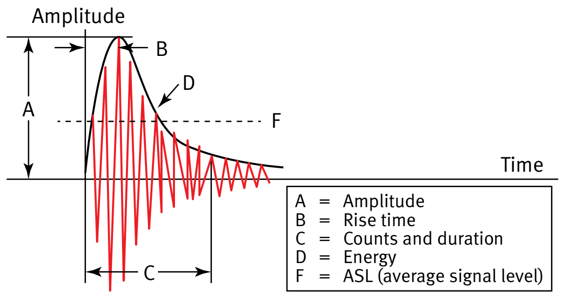

Figure 3. Analog response from an acoustic emission sensor showing the features of the waveform.

When designing a structure, the materials selected are chosen for their specific properties, which enables them to meet the operational requirements for a specific operating environment. Factors to consider include operating temperature, resistance to corrosion, ductility, fracture toughness, and maximum design loads. It is important to understand how each of these factors affect the acoustic emission signal response. Because the material properties play an integral role in the acoustic emission signal that is generated, it is critical that the data is not analyzed using established "norms" from generic studies of other random samples of the same material. The properties of materials can change over time in response to various environmental factors, so the more information that is known about the history of the structure, the more accurate the AE data analysis will be. If the results of other studies are to be used in the analysis, the data should be taken from samples that share the same history of usage and environmental factors.

One historical factor that is sometimes ignored is the age of the structure. A number of very useful studies have been conducted to determine the fracture toughness of a particular type of material. Most of these studies have been done on virgin material that has not experienced any fatigue loading. In these studies, the structure is loaded once to remove or neutralize residual stresses, and then the structure is loaded a second time for evaluation (ASME 2019a, 2019b; Fowler et al. 1989). While this is an effective method for determining the fracture toughness of a material sample, the data obtained from the virgin material cannot be applied generically to a structure that has undergone stress loadings over time. Materials that have undergone significant stress changes for any reason will develop metal fatigue, and the acoustic emission signature as well as the fracture toughness will change.

Another historical factor that must be considered is the structure's load history. The Kaiser effect is an acoustic emission phenomenon defined as the absence of detectable acoustic emissions until the previously applied stress level is exceeded. The Kaiser effect is well described in many of the early papers on AE. Briefly explained, this is the irreversible effect on the structure being tested. This effect can, however, be nullified by temperature and metal fatigue due to operating conditions. For this reason, it is strongly recommended that the test load be based on the history of the structure. As a guide, the test load should be at least 5% higher than the highest operating load or pressure that the structure has seen over the last six months (this information can be obtained from the operational records of the structure).

The basic crack behavior can be categorized into three major sectors: initiation, subcritical growth, and catastrophic failure. Each stage has its own distinct acoustic emission hit signature (Figure 4).

Crack Initiation

Crack initiation is illustrated in the first stage of Figure 4. Cracks may start for several reasons. Among these are corrosion pitting, mechanical damage, defects in the base metal or weld, and metal fatigue. The acoustic emission hit signature may be small or large depending on the brittle state and fracture toughness of the material. For example, the acoustic emission waveform for normal pressure vessel steels that have seen service is likely to show an amplitude in the region of 60 to 70 dB and energy level of 60 to 100 (for a reference gain of 23 dB) for sources close to the AE sensor. (The farther the distance between the sensor and the source, the lower the levels will be.)

Subcritical Crack Growth

Subcritical crack initiation is illustrated in the second stage of Figure 4. The incremental growth of the crack is a step function. During this phase, the energy usually increases as the crack approaches the catastrophic phase. Practical AE tests show an increase in both the energy and the amplitude of the acoustic emission hit. It is exceedingly difficult to be specific as to what the values will be, as this again is influenced by the material. For common pressure vessels (steels), at a given distance early in the subcritical stage, the AE values are likely to be higher than 70 dB AE with an energy level greater than 100. Closer to the catastrophic phase, the AE value will be between 80 and 100 dB with an energy level exceeding 250. One good indicator is when the hit/per energy ratio exceeds 250; then it is time to examine the structure in the area near the AE sensor using other suitable NDT methods such as UT. Another good indicator that the structure is in trouble is the increase in the level of acoustic emission hits recorded during the procedural hold periods (normally 10 min during 50%, 65%, and 85% of the pressure load, and then 30 min during the final test load).

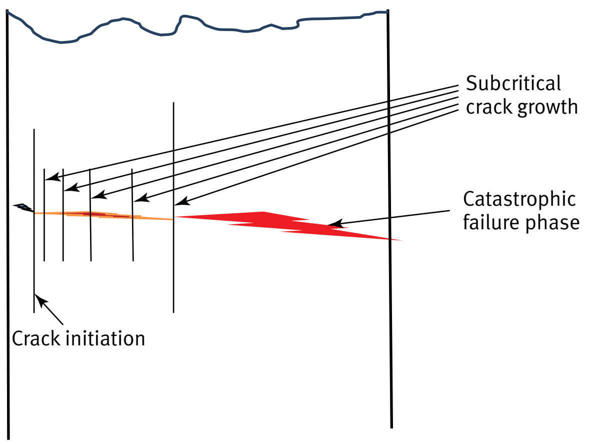

Figure 4. Basic crack behavior: crack initiation, subcritical crack growth, and catastrophic failure.

Catastrophic Failure

An example of catastrophic failure is shown in the final stage of Figure 4. In this phase, the structure is no longer able to retain its form and could lead to serious damage. This phase is to be avoided as much as possible due to economic impacts and safety issues.

Evaluation by Material Type

Following are some of the important characteristics or conditions that play a role in the acoustic emission signature evaluation process by material type. This information is based mostly on "in the field" experience and verification of AE results.

- Steel: strength, fracture toughness, ductility, age, presence of residual stress, presence of weld defects, and temperature.
- Austenitic steel: strength, fracture toughness, ductility, age, presence of residual stress, presence of weld defects, and temperature.
- Composite structures: this includes materials such as fiber-reinforced plastic (FRP) and concrete. The failure mechanisms of FRP include fiber breakage, delamination (debonding), and matrix cracking, while the failure mechanisms of concrete include alkaline damage cement cracking and the like.
- Cast iron: there are two major types of cast iron—spheroidal graphite (SG) and gray cast iron. The SG cast iron is more ductile than the gray cast iron. When testing cast iron, it must be noted that this material is more brittle than the steels used in pressure vessels and therefore the acoustic emission signals are going to be much higher. A small crack will record activity in the order of +80 dB.

In Part 2 of this article, the influence of the various materials used in construction and their effects on the AE data will be discussed.

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