AE Testing (AT)

Fundamentals - Equipment – Data Analysis (Overview)

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1 Overview

Acoustic Emission (AE) Analysis is an extremely powerful technology that can be deployed within a wide range of applications of non-destructive testing: metal pressure vessels, piping systems, reactors and similar. This paper focuses on this kind of applications. Other types of applications shall only be mentioned briefly:

- Non-destructive testing of heavily mechanically stressed components or complete structures of fiber-reinforced plastics or composites, as used e.g. in the aerospace industry.
- Material research (e.g. investigation of material properties, breakdown mechanisms, and damage behavior)
- Inspection and quality assurance, e.g. monitoring of welding and wood drying processes, series inspection of ceramic components, scratch tests and more.
- Real-time leakage test and location within various components ranging from a small valve up to a tank bottom with diameter of 100 m.
- Geological and micro-seismic research.
- Detection and location of high-voltage partial discharges in large transformers.

Acronyms used are ‘AE’ for ‘Acoustic Emission’ (according to NDT-norm EN 1330-9) and ‘AT’ for ‘Acoustic Emission Testing’ (according to EN473-2000).

Vallen - Systeme GmbH
Schäftlarner Weg 26
D - 82057 Icking (Munich), Germany
ISO 9001 certified by TÜV CERT
Tel: +49 8178 9674-400
Fax: +49 8178 9674-444

email: info@vallen.de
http://www.vallen.de

2 Sources of AE

All solid materials have a certain elasticity. They become strained or compressed under external forces and spring back when released. The higher the force and, thus, the elastic deformation, the higher is the elastic energy. If the elastic limit is exceeded a fracture occurs immediately, if it is a brittle material, or after a certain plastic deformation. If the elastically strained material contains a defect, e.g. a welded joint defect, a non-metallic inclusion, an incompletely welded gas bubble or similar, cracks occur at heavily stressed spots, rapidly relaxing the material by a fast dislocation. This rapid release of elastic energy is what we call an AE event. It produces an elastic wave that propagates and can be detected by appropriate sensors and analyzed. AE testing detects and interprets the acoustic events resulting from these crack processes and can identify, locate, and display a beginning damage to the tested object within very short time.

3 AE-Analysis – an Integral Testing Method

A short, transient AE event is produced by a very fast release of elastic energy, actually a local dislocation movement. This local dislocation is the source of an elastic wave that propagates into all directions and cannot be stopped any more. It is similar to an earthquake with the epicenter at the defect, but in microscopic dimensions.

It is possible to monitor 100 % of a relatively large surface with a small number of sensors. It is not necessary to move the sensors above the surface to locate a defect.

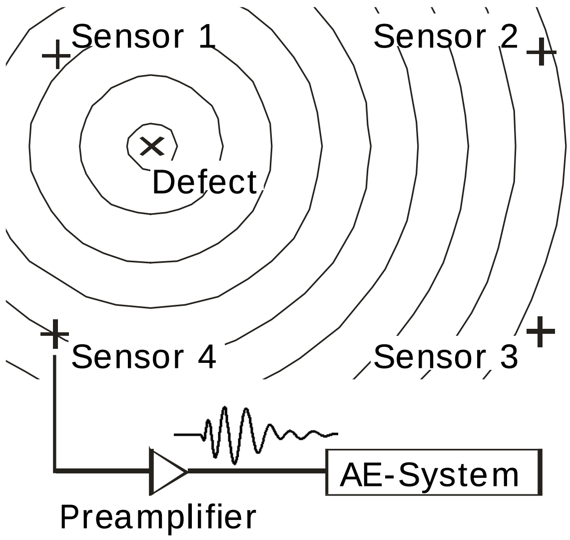

Figure 1: *Propagation of sound*

4 AE-Analysis – a passive Testing Method

AE testing is a **passive, receptive** technique analyzing the ultrasound pulses emitted by a defect **right in the moment of its occurrence**. In contrast to the ultrasound technique one does not measure the response to an artificial and repeatable acoustic excitation of the test object. Instead, the sound signals produced by each growth of a defect are evaluated. Each growth of a defekt is a unique event and cannot be reproduced

5 AE-Analysis – a Dynamic Real-Time Testing Method

AE occurs when a crack grows or when crack borders rub against each other, e.g. when a crack closes after relaxation of the test object. Usually, the test object must be stressed mechanically exceeding the operating level in order to have local defects grow and emit acoustic emission. Therefore AE analysis is the appropriate technique especially in those cases, where test objects are anyway stressed more than under normal conditions, e.g. with pressure vessels test. The AE-analysis “listens” to the defects right at the moment of their occurrence, thus, in real-time. Because of this real-time monitoring, the AE testing method can be used as a warning system to avoid a failure of the system with possibly disastrous consequences for environment and testing objects.

email: info@vallen.de
http://www.vallen.de
ISO 9001 certified by TÜV CERT
Tel: +49 8178 9674-400
Fax: +49 8178 9674-444
Vallen - Systeme GmbH
Schäftlarner Weg 26
D - 82057 Icking (Munich), Germany

6 The AE process chain

As can be seen in figure 2, mechanical stress has to be produced within the test object, which is usually done by applying external forces. The behavior of the material and the starting point of the release of elastic energy, e.g. by crack formation, are influenced by the material properties and the environmental conditions. The elastic wave propagating through the material is detected and converted into the electrical AE signal by the AE sensors. The AE system processes the AE signal, converts the detected bursts into feature data sets, determines the source locations, calculates statistics, and displays them graphically and numerically in real time.

So-called parametric channels measure the environmental conditions as well as the external load as reference parameters for the detected AE.

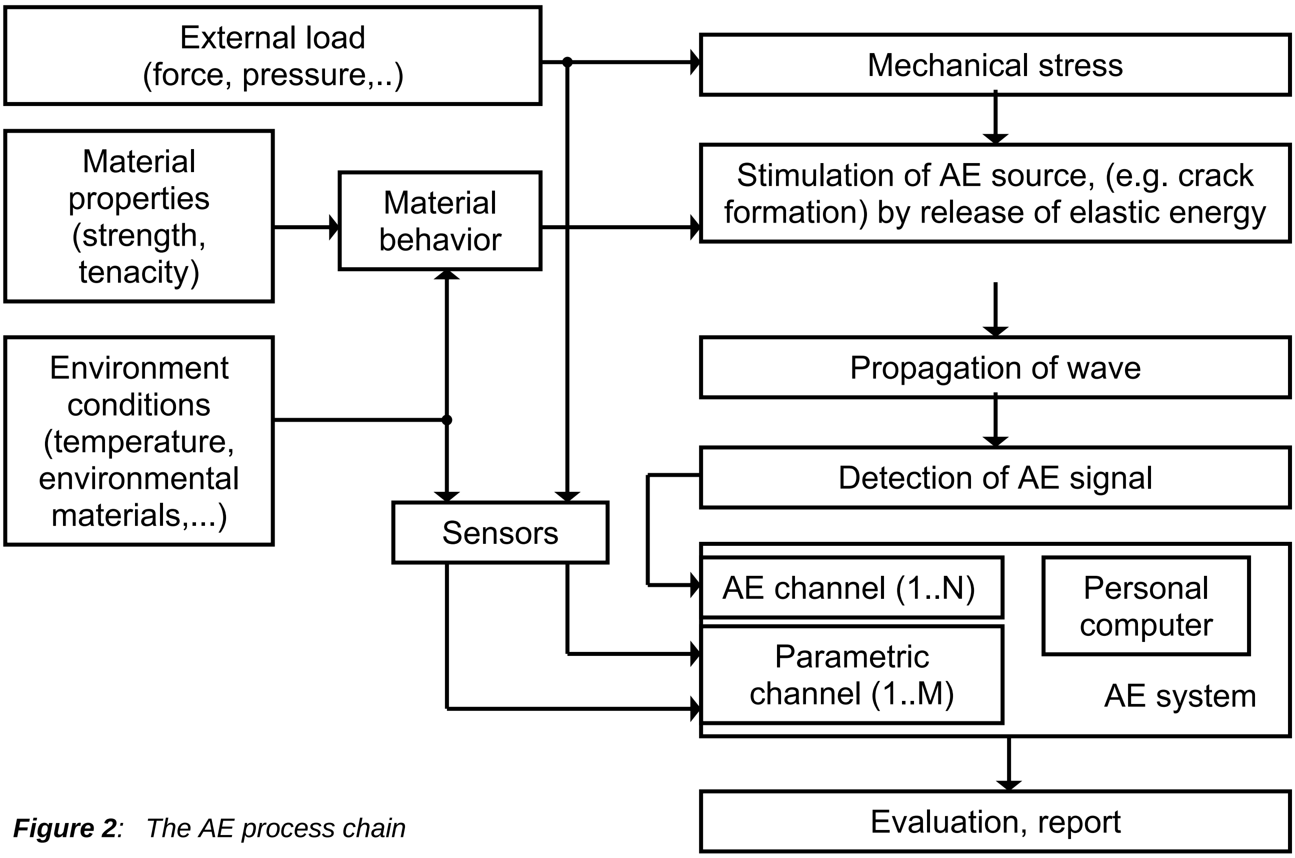

***Figure 2**: The AE process chain*

7 Transient and Continuous Signals

Basically, there are two types of AE signals, transient and continuous signals. With transient signals, also called bursts, the begin and end of the signal deviate clearly from the background noise. With continuous signals, we can see amplitude and frequency variations but the signal never ends. In figure 3, both types of AE signals are displayed.

The useful signals for AE testing at large pressure vessels are burst type signals, e.g. originating from fracture or crack growth. Continuous signals are mostly unwanted (noise) signals such as friction or flow noise. But even burst signals can be interfering signals, e.g. short friction noise or electrical spikes. At the best the background noise is just the electronic noise of the preamplifier or the sensor.

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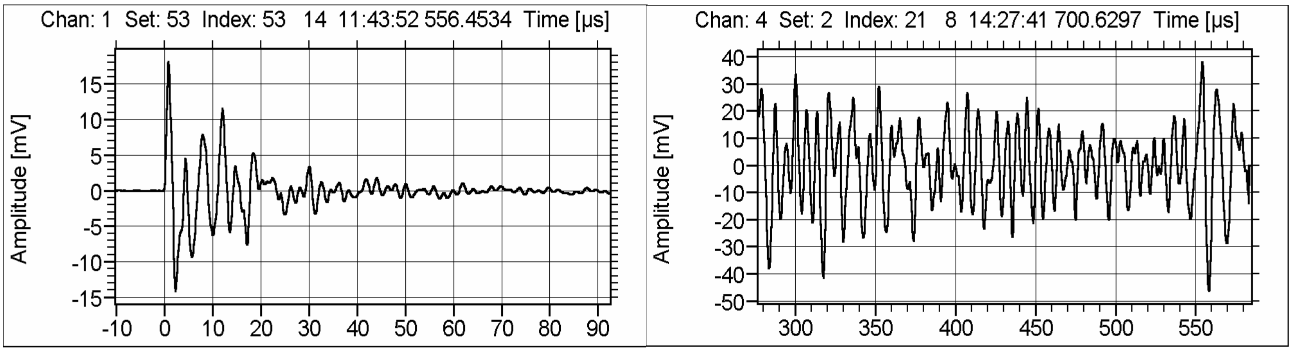

Figure 3: *Transient (left) and continuous (right) AE signal*

8 AE Parameters

In very few cases, AE testing is based on only a few bursts. In general, some hundreds or thousands of bursts are recorded for statistic evaluation. The statistical evaluation of waveforms is more difficult than that of certain waveform features (parameters). One has to determine the most important parameters of the waveforms in order to compare the results of the structure under test with a database of defect-free and defect containing test objects. The most commonly used features are:

- Arrival time (time of first threshold crossing, needed for location calculation)
- Peak amplitude
- Rise-time (time between first threshold crossing and peak amplitude)
- Signal duration (time between first and last threshold crossing)
- Number of threshold crossings (counts)
- Energy (integral of the squared (or absolute) amplitude over time of signal duration)
- RMS (Root Mean Square) of the continuous background noise (before the burst)

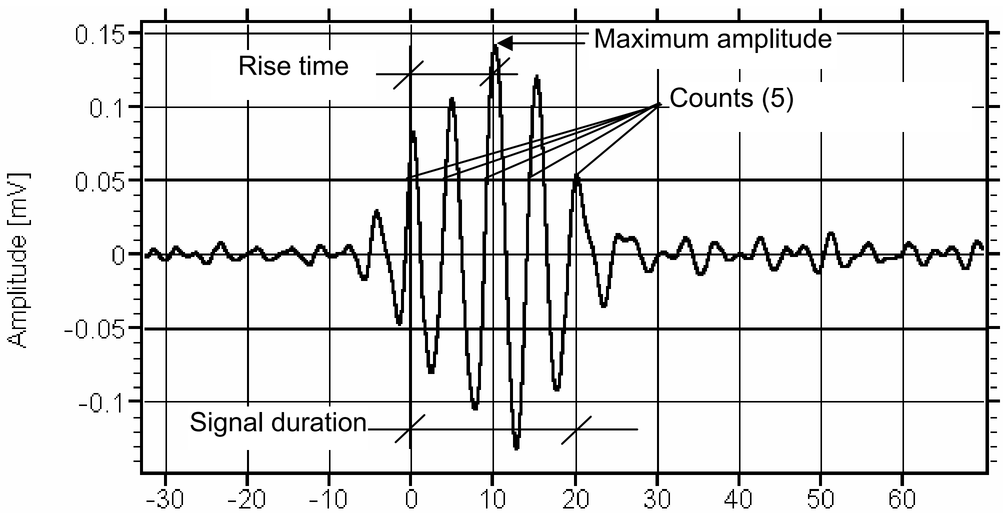

Figure 4: *Features of transient signals*

email: info@vallen.de
http://www.vallen.de
ISO 9001 certified by TÜV CERT
Tel: +49 8178 9674-400
Fax: +49 8178 9674-444
Vallen - Systeme GmbH
Schäftlarner Weg 26
D - 82057 Icking (Munich), Germany

AE bursts are not only produced by the defects we are looking for, but can also originate from disturbances, such as peaks of the background noise, which sometimes exceed the threshold. Therefore, it is very important to determine those characteristics that lets us distinguish the wanted from the unwanted bursts.

The peak amplitude is one of the most important burst features. Crack signals show medium to high amplitudes and have durations of some 10 µs, depending on the test object's properties.

In most cases, bursts with less than 3 threshold crossings and durations less than 3 µs can be regarded as unwanted signals. Most of the bursts with low amplitudes and long duration are friction noise. Very short signals may indicate electrical noise peaks, especially, if they arrive at all channels at the same time.

With logical filters one can separate bursts on the basis of those burst features in a flexible way. This must be done carefully: Always make sure not to miss inadvertently important bursts.

9 The AE Measurement Chain

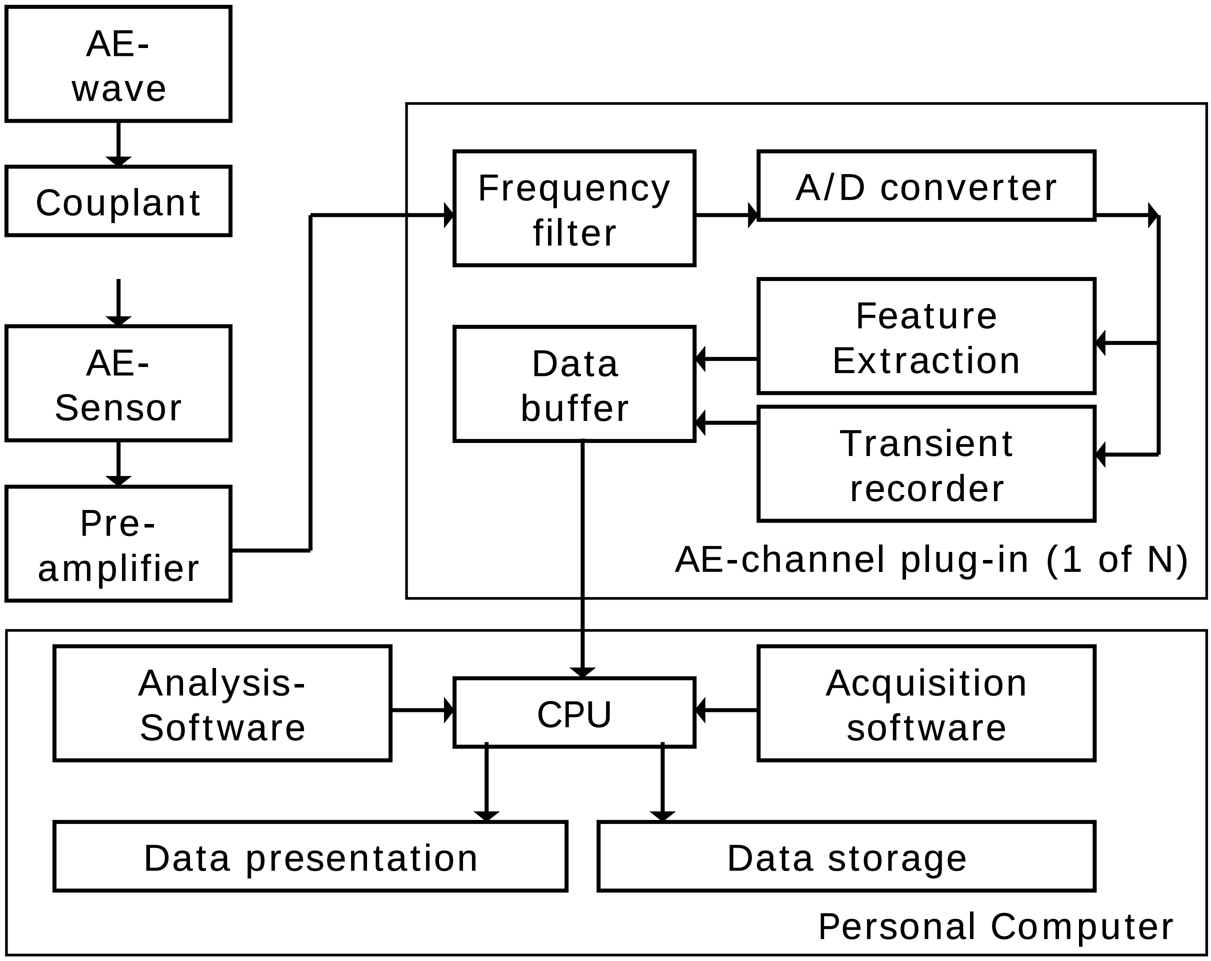

Figure 5: *The AE measurement chain*

The diagram in figure 5 shows the schematic of an AE measurement chain, from the couplant to the PC.

Piezo-electric sensors have proved to be most appropriate for all types of AE testing. They are robust and extremely sensitive. The optimal frequency range to be chosen depends on the expected kind of AE-sources and the conditions of wave propagation, wave attenuation and distances. When testing metal vessels for integrity, the frequency range 100 to 300kHz is usually selected. Testing concrete and plastic materials requires often the selection of lower frequencies. If disturbing noise can not be eliminated by other means, and the source mechanism is appropriately wide band, the selection of higher frequencies may improve the

Vallen - Systeme GmbH
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signal to noise ratio, on costs of shorter detection distance. The selected frequency range is defined by the sensor, the frequency filters in the preamplifier and in the AE-channel plug-in board.

The demand on the complete measurement chain and especially on the A/D-converter, with respect to dynamic range and sample rate, is enormous: Signals from weak sources in large distance shall be discriminated from the electronic noise. Signals from strong sources in short distance must not saturate the measurement range. Thanks to the progress in microelectronics, such demands became feasible during the most recent years. Figure 6 shows a low and a high amplitude signal, as it was digitized by the AE-System (AMSY4, Vallen-Systeme) in the measurement range of +/-100mV. The left signal shows a burst amplitude of about 40µV, the right one of about 40 mV, a 1000 times higher amplitude.

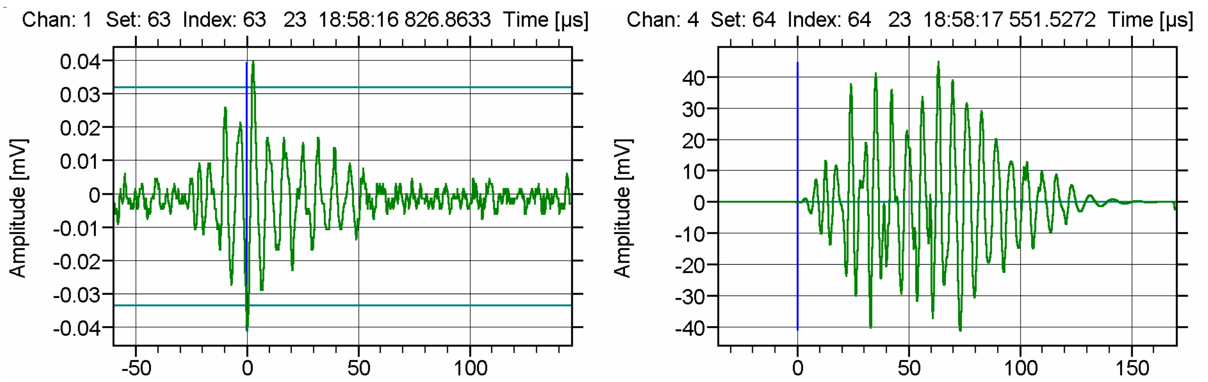

Figure 6: *AE signal dynamics - bursts of modern A/D converter*

These A/D-converters have a dynamic range of 16 bit. This corresponds of a ratio of 1 to 65.397, or 1.5 mm to 100 m. The continuous sample rate is 10 MHz, i.e. each channel produces the huge amount of 10 million measurement values per second, which are processed by the feature extraction processor in real-time. The transient recorder (Figure 5) is used to store all samples of the waveform of such bursts whose characteristics indicate significance. The diagrams in Figure 6 and 7 are only possible because of the transient recording capability.

10 Location Calculation Based on Time Differences

The determination of the source location of each event is an essential element of AE testing. The distance differences between a source (defect) and different sensors are equal to *Arrival Time Difference * Sound Velocity*.

Figure 7 shows the waveforms and their different arrival times taken from the sensor source setup of figure 1. The exact time of the source can not be measured. Only the differences of the arrival time (Δt) between the sensors can be measured. The distance difference between the source and two sensors is calculated by Δt*v. All points having a constant difference between their distances to two fixed points (sensors) form a hyperbola. Figure 8 shows three hyperbolae that correspond to the measurement in Figure 7. Each hyperbolae represents all points with the calculated distance difference between two sensors. At the point of intersection of the three hyperbolae there is the wanted source position.

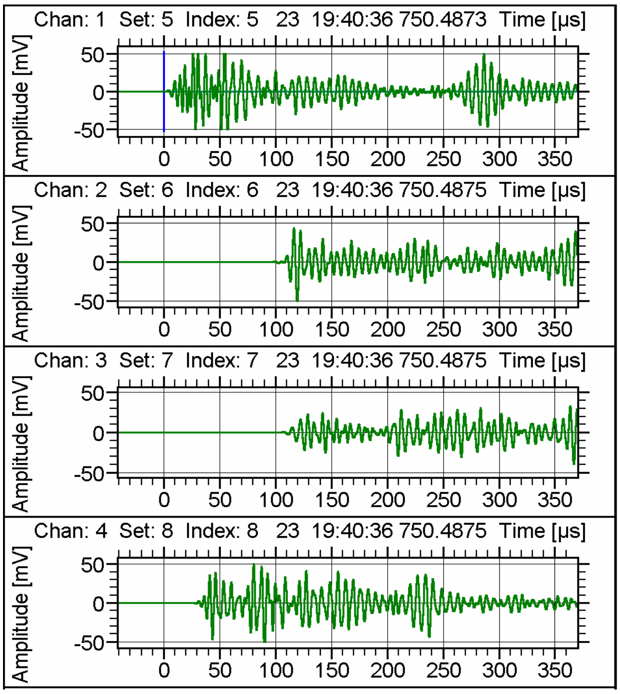

Figure 7: *Arrival Time Differences*

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11 Clustering

Usually, the results of a location calculation are plotted in a point diagram with e.g. a background picture of the test object.

Figure 9 shows an example for a spherical storage tank for natural gas. Each symbol indicates a location result where the color and shape of the symbol indicates a certain amplitude range.

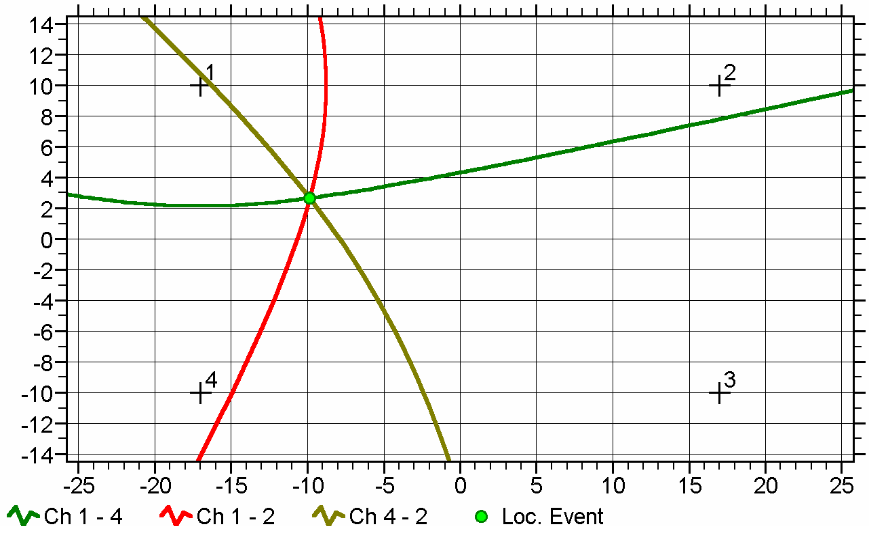

Figure 8: *Hyperbola intersection with 3 hit sensors*

Concentrations of location results are called clusters, shown in figure 9 as big circles. The color of the cluster circle indicates the number of located events within the cluster. Location clusters comprising a high number of events indicate places of repetitive AE-sources. This might be potential defects or disturbers. Sometimes these sources can be quickly identified, e.g. as rubbing materials, annexes etc. If it is not possible to identify a source as a disturber, it has the potential of a defect and is to be tested by others NDT methods.

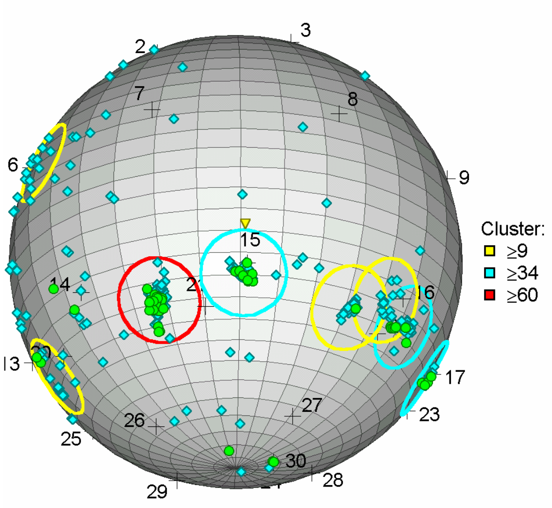

Figure 9*:* *Spherical Location*

12 Conclusion

This paper can only give an overview of the AE testing method. Its main purpose is to present the progress of the equipment technology made during the last years.

The high level of modern computer technology and the user friendly Windows-Software can process and display some 100 Clusters per second in real-time. The increase of the technology during the last years increased also the number of successful AE applications. The speed of data acquisition and analysis has increased by a factor of 1000 and more over the last decade. One should not measure the potential of the AE method at some disappointing experiences with equipment made 10 years before. This testing-method has reached maturity in many applications.

The acceptance of the AE testing-method has also improved. Since 1999 the DGZfP offers AE-testing courses (AT) in accordance to EN473-2000. AT is a component of the new Z-courses for the Level-3-aspirants. A couple of CEN-Norms concerning AT have been developed, also showing the good consensus between the men of knowledge.

The use of AT will continuously increase and will be considered more and more for pressure vessel examinations as well as for other applications, e.g. testing of flat tank bottoms.

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