AE Testing

Fundamentals,

Equipment,

Applications

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1 Overview

AE-Analysis is an extremely powerful technology that can be deployed within a wide range of usable 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.

This introduction applies to the NDT practitioner, who has not yet much experience in the field of AE. This contribution shall introduce the principles, capabilities, and limitations of AE.

In some cases, AE testing and hydro test complement each other but more and more, they become competing techniques. As we will see, the AE analysis provides additional information compared to the hydro test, e.g. whether a test object has weak spots and where they are located, even if they are not yet relevant under security aspects. So, AE testing is the more valuable technique with respect to the acquisition of information. Therefore it should be taken into consideration for any kind of repetition tests of large vessels. Sometimes in parallel to the hydro test.

Figure 1 shows a vessel with a length of 25 m and a diameter of 4 m, which is undergoing detailed AE measurements within a research project. (Source: CRAFT SYNTHESIS REPORT BRE-CT96-5047, CETIM, France)

Acronyms used are ‘AE’ for ‘AE’ (according to EN 1330-9) and ‘AT’ for ‘AE Testing’ (according to prEN473-2000).

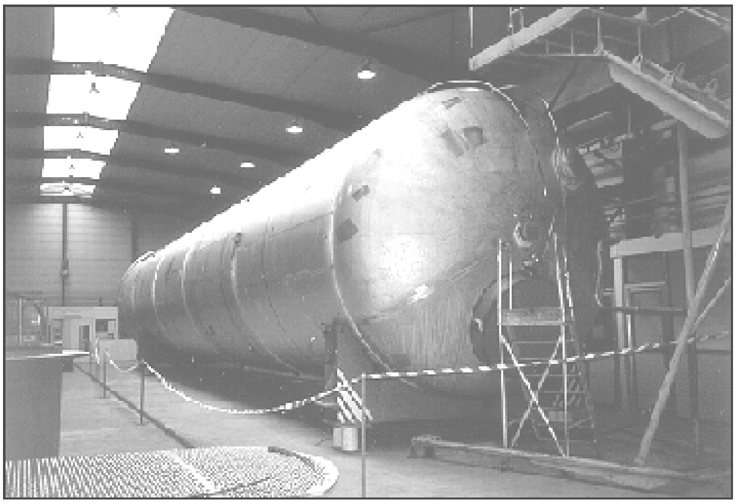

Figure 1: *Online testing of a stainless steel vessel with a length of 25 m and a diameter of 4 m*

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1.1 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, incompletely welded gas bubble or similar, cracks may 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. The impact at its origin is a wideband movement (up to some MHz). The frequency of AE testing of metallic objects is in the range of ultrasound, usually between 100 and 300 kHz.

Everybody knows the sound of breaking glass but it is not as widely known, that tiny cracks in steel or other solid materials emit very intense ultrasound bursts. 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.

During plastic deformation, dislocations move through the crystal lattice. These movements also produce AE but most of these processes (except for twinning) only have very low amplitudes, which can be measured reliably only at a short sensor distance and in laboratory environment. Most of these processes produce continuous signals rather than short bursts. Bursts are pulses or short wave packets, the type of signals AE testing is based on.

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 defects are evaluated, every growth of a defect is a unique event and can’t be exactly reproduced again.

The AE analysis is a **dynamic technique**. 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 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. the first proof test or re-qualification tests of pressure vessels.

Also corrosion, e.g. at the bottom of oil tanks, produce burst AE that propagates through the liquid oil to the tank wall, where it can be detected. With leakages, AE is e.g. produced by turbulent flow in the leak itself or by particles rebounding from the tank support. Burst AE from leakages will occur mainly at high pressure. Small pressure differences mainly cause laminar flow that emits continuous AE with low amplitudes and small propagation distances.

Also, if due to mechanical loading composites de-laminate, glue joints detach, fiber reinforcements break, etc. AE is produced, which can be analyzed for testing or monitoring these structures.

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1.2 AE Signals Propagate – Even from Inaccessible Locations

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 with microscopic dimensions.

On flat surfaces, the wave propagates in terms of **concentric circles** around its source and can be detected by one or more sensors. During propagation, the wave is attenuated. The maximum distance, where an AE event still can be detected depends on various parameters, e.g. on the material properties, the geometry of the test object, its content and environment, etc. On flat or cylindrical metal surfaces, events can still be detected at a distance of several meters, which is one of the great advantages of this technique. AE testing can reliably cover areas which are not accessible by other testing methods.

Tank bottom testing preferably analyzes waves which propagate through the liquid from the source to the tank wall.

In liquid filled pipelines the maximum distance AE events can be detected is usually longer than in gas filled tubes, because the AE signal attenuates less in the liquid volume than in the thin tube wall.

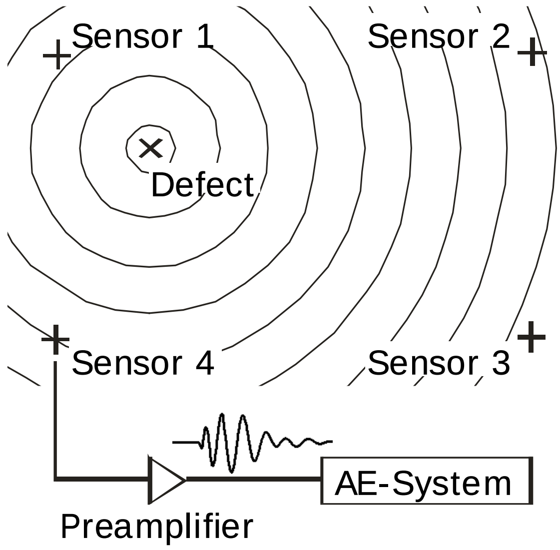

Figure 2: *Propagation of sound*

Depending on the position of the AE source, the wave reaches the sensors with certain delays. The position of the source can be calculated using the different arrival times. This is called 'location calculation'. Thanks to the high computing power of modern PCs, the location calculation can be done in real-time, i.e. during the examination, and the results can be displayed immediately, which will be discussed in detail in one of the following chapters.

1.3 The AE Process Chain

This paper will just give an overview, as a detailed discussion of the single steps would exceed its scope. A process chain always exists at AE testing. The process chain basically consists of the following links:

1. Test object and application of load: Produce mechanical tensions
2. Source mechanisms: Release elastic energy
3. Wave propagation: From the source to the sensor
4. Sensors: Converting a mechanical wave into an electrical AE signal
5. Acquisition of measurement data: Converting the electrical AE signal into an electronic data set
6. Display of measurement data: Plotting the recorded data into diagrams
7. Evaluation of the display: From diagrams to a safety-relevant interpretation

As can be seen in figure 3, 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 environment 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 received wave packets into feature data sets, determines the source locations, calculates statistics, and displays them graphically and numerically.

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

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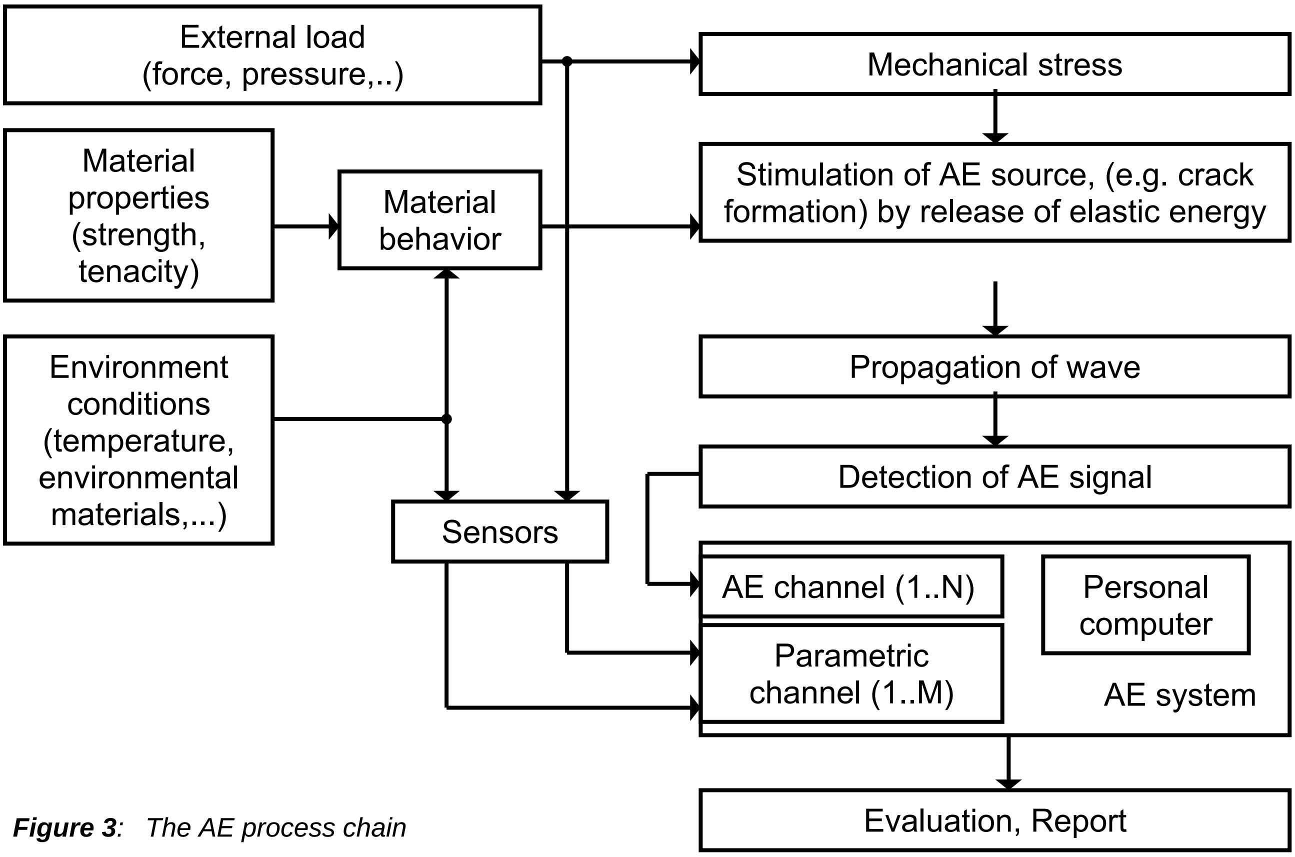

***Figure 3**: The AE process chain*

1.4 Glossary

This paper refers to certain standard terms (EN1330-9) defined by a workgroup of the CEN TC138:

(n.d.: not defined by the standards, just added for better understanding):

AE (AE): A transient elastic wave produced by release of (elastic) energy or during certain processes
AE-event: Physical event producing AE, e.g. crack formation
AE-source: Physical origin of one or more AE events. This can e.g. be a crack growing step by step. Each growing of the crack is an AE event.
AE signal: The electrical signal of the sensor resulting from AE
Transient signal, burst: AE signal with clearly detectable start and end
Hit: A burst detected by the AE system
AE-activity: Occurrence of AE signals as a result of AE
AE-intensity: The strength of the AE events in units of e.g. energy or amplitude (n.d.)
AE channel: Single AE sensor including the associated instruments for the acquisition and measurement of the AE signals = measurement chain
Multi-channel system: System providing multiple AE channels, e.g. for source location, or for examining areas too large for one sensor (n.d.)

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1.5 Transient and Continuous Signals

Basically, there are two types of AE signals, transient and continuous signals. With transient AE signals, also called bursts, start and end points deviate clearly from background noise. With continuous AE signals, we can see amplitude and frequency variations but the signal never ends. In figure 4, an example of both types of AE signals are shown.

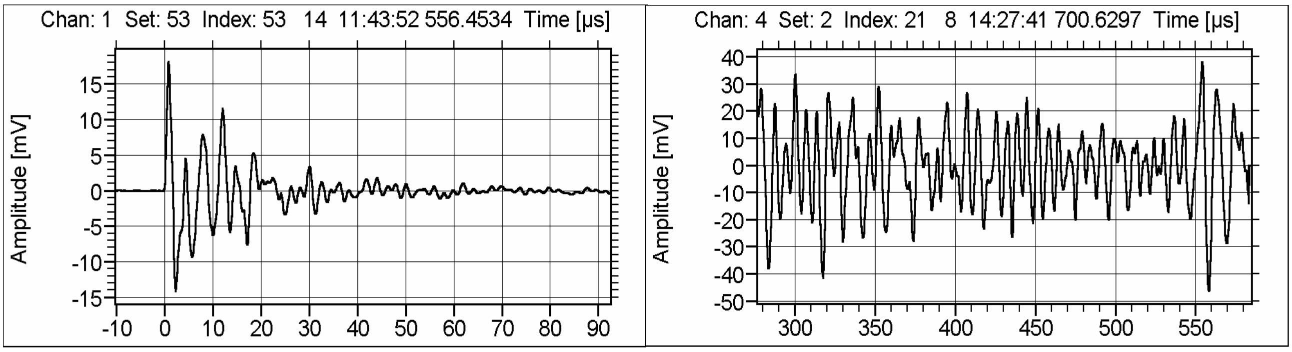

Figure 4: *Transient (left) and continuous (right) AE signal*

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.

1.6 Determination of the Arrival Time

One of the very important tasks of an AE systems is to convert the AE bursts into compact data sets and to eliminate the background noise (which is more or less continuous).

For this, modern AE systems use detection thresholds. The threshold has to be set to the right value by the user. If the AE signal exceeds the threshold in either positive or negative direction, this means the start of a hit (a hit is a detected burst).

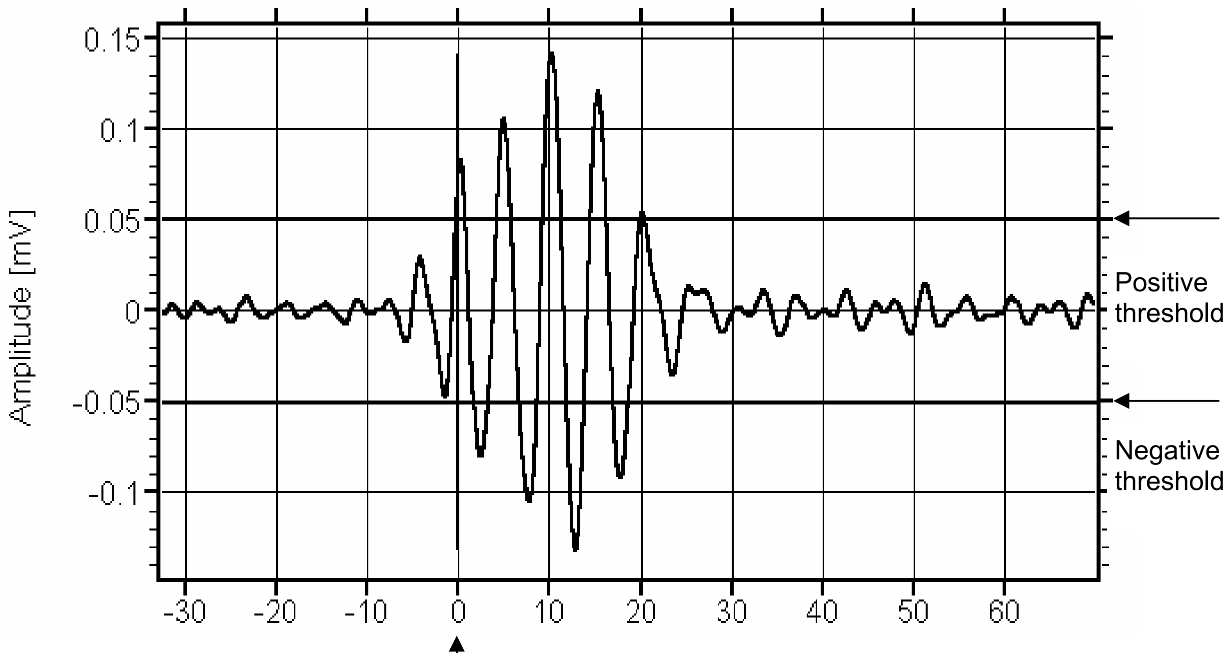

Figure 5 : *Determination of the arrival time*

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The time of the first threshold crossing is called "arrival time of the burst" and is needed for location calculation. Waveforms like in figure 4 and 5 are produced by joining many single points called 'samples'. They correspond to single measurements at constant time intervals. Digital systems sample the AE signal e.g. every 100 ns, which means 10 million times a second. The unit of the time axes of the above diagrams is µs, i.e. every 10 µs interval contains 100 samples. A wave packet of 100 µs as shown above, is made of more than 1000 samples, which shows the huge amount of memory required for a single burst.

1.7 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. Statistical evaluation of waveforms themselves is difficult, but certain features of waveforms can be evaluated statistically. One has to determine the most important parameters of each waveform in order to compare the results of the structure under test with those of defect-free test object and with those of a defective test object. The most commonly used features are (see figure 6):

- Arrival time (absolute time of first threshold crossing)
- Peak amplitude
- Rise-time (time interval between first threshold crossing and peak amplitude)
- Signal duration (time interval between first and last threshold crossing)
- Number of threshold crossings (counts) of the threshold of one polarity
- Energy (integral of squared (or absolute) amplitude over time of signal duration)
- RMS (root mean square) of the continuous background noise (before the burst)

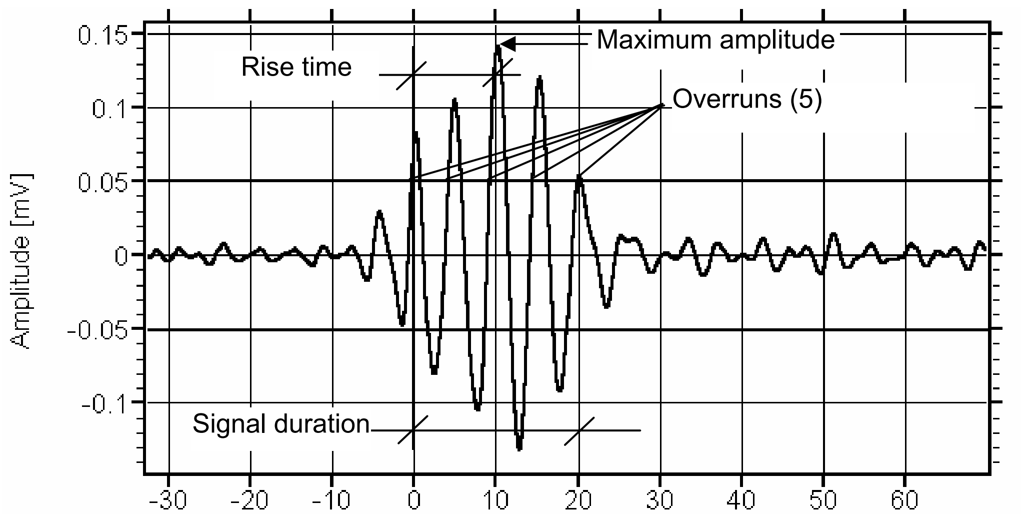

Figure 6: *Features of transient signals*

AE bursts are not only produced by the defects we are looking for but can also originate from drop-ins such as peak values of the background noise, which sometimes exceed a low threshold. Therefore, it is very important to determine those characteristics that 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.

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1.8 External Parameters

External parameters, such as pressure or temperature are used as reference for the measured AE data. A parametric channel is a DC signal input, which represents the actual value of an external parameter, such as pressure, temperature, etc.. Figure 7 shows an example for a common display of the total number of events and the pressure vs. time.

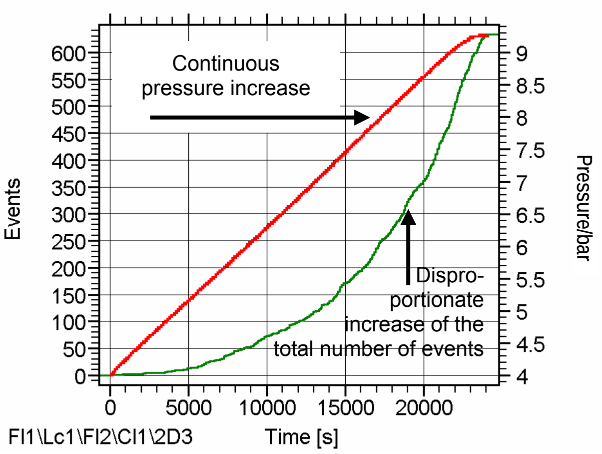

Figure 7: *Events (left axis) and pressure (right axis) vs. time*

2 The AE Measurement Chain

The diagram in figure 8 shows the schematic of an AE measurement chain, from the couplant up to the PC.

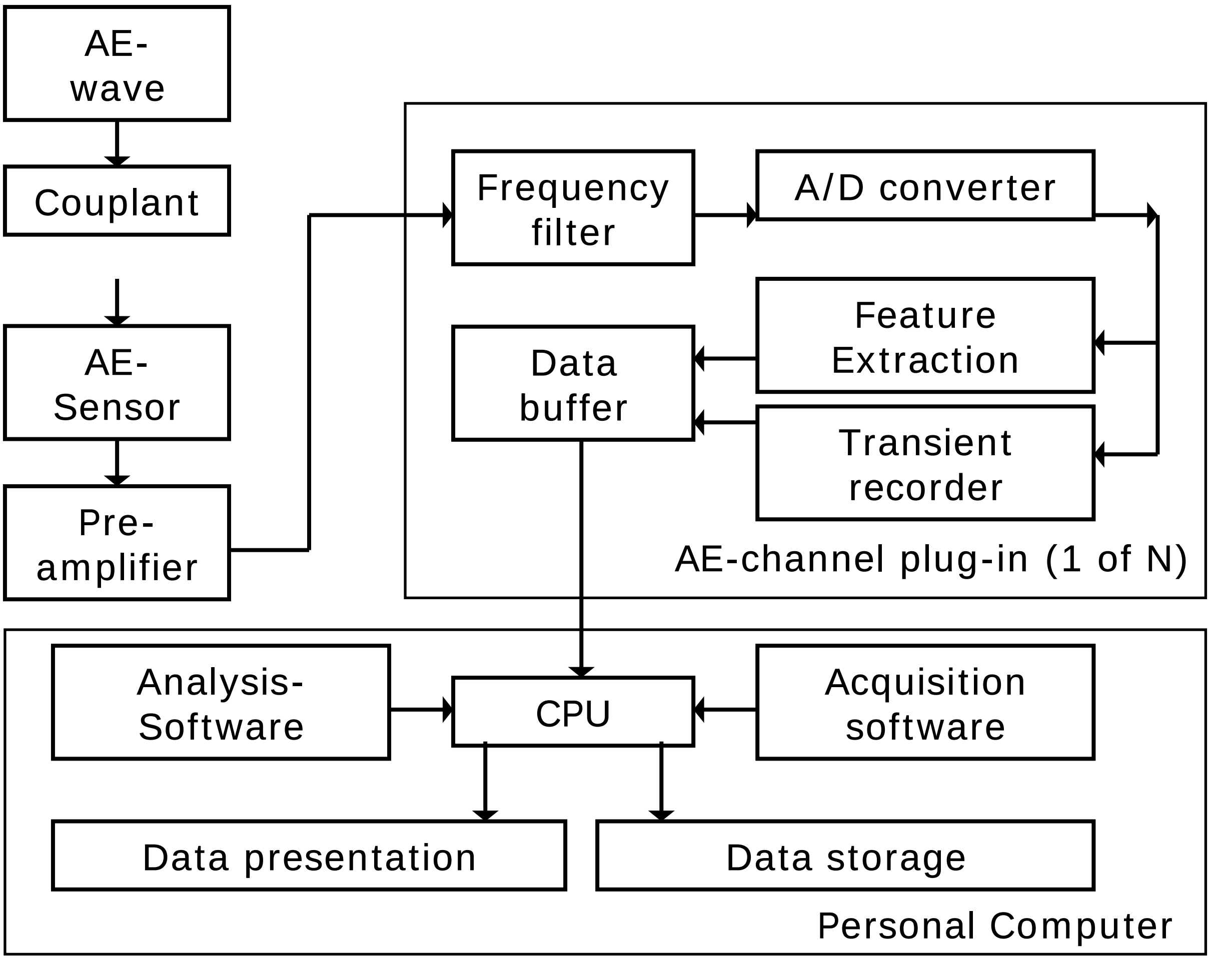

Figure 8: *The AE measurement chain*

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2.1 The Couplant

The coupling agent is crucial to the quality of sensor coupling. It shall provide a good acoustic contact between the sensor and the surface of the test object. Make sure to select the appropriate couplant, which does not corrode the test object's surface, and which fits to the given temperature. Usually, silicone grease (high vacuum grease), oil, or glue are used.

Note: Some of the glues become brittle and produce strong cracking noise with smallest movement of the test object! Therefore it is recommended to glue an elastic sensor hold down at the sample and to fix the sensor with an elastic device, e.g. a rubber band, against the test object's surface.

For best coupling results, do not take too much of the couplant and make the layer as thin as possible by firmly pressing the sensor against the test object's surface. After attaching the sensor(s), the quality of the coupling must be verified (pencil lead break, automatic coupling test). If required, the coupling procedure must be repeated.

2.2 Hsu-Nielsen-Source

The pencil lead break (also termed as Hsu-Nielsen-Source or HSN-Source) is a frequently used artificial acoustic source, which produces well reproducible acoustic events. A pencil lead (usually 2H, 0,3mm) is broken against the structure under a defined angle. A special shoe (specified e.g. in ASTM standard E976) aids in breaking the lead consistently. The Hsu-Nielsen-Source is used e.g. to verify the sensor coupling or to determine the acoustic attenuation of a structure.

2.3 The Sensors – Converting the Mechanical Wave into an Electrical AE Signal

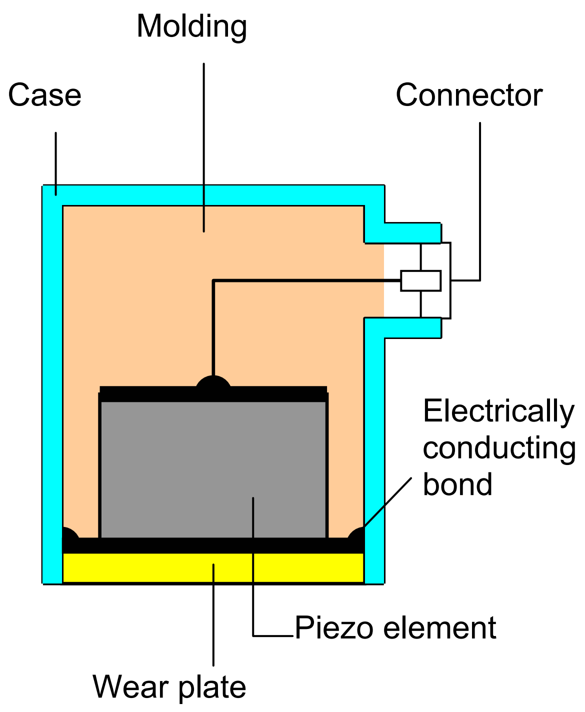

Figure 9: *Basic setup of an AE sensor*

Piezo-electric sensors have proved to be most appropriate for AE testing. They are robust and more sensitive than other sensor techniques, e.g. capacitive, electro-dynamic, or laser-optical sensors.

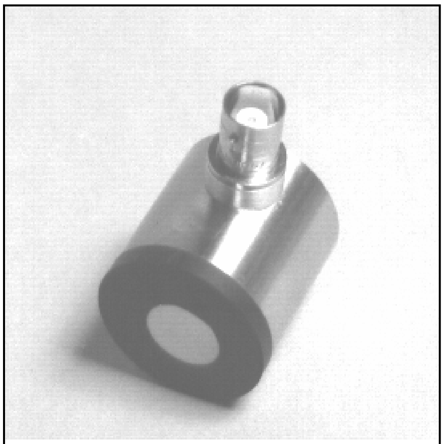

Figure 10: *AE sensor with integrated pre-amplifier*

When testing metal vessels for integrity, frequencies between 100 and 300kHz are usually most interesting. The sensors used for this frequency range have a resonance at about 150 kHz and cover the range of 100 – 300 kHz with a variation of sensitivity of about 6 dB. The resonance frequency determines indirectly the spatial range of the sensor:

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High frequencies attenuate faster, so they have a smaller detection distance. Background noise coming from longer distances consist only of frequency components below 100 kHz, so they have only small influence on the measurement chain tuned to 100 – 300 kHz.

For testing tank bottoms, sensors with a high sensitivity in the range down to 25 kHz are required, because signals run over long distances. Hence it is very important to find and turn off potential noise sources.

Often the sensors already contain a preamplifier and are attached to the objects using magnetic holding devices. The amplified AE signal is transmitted to the AE system via a signal cable. Usually, the $28V_{DC}$ power supply for the pre-amplifiers is fed through the signal cable. The signal cable can have a length of several 100 m.

The sensitivity of piezo-electric sensors can reach values of up to 1000V/µm. A displacement of 0.1 pm generates 100µVpk then and can be well distinguished from the electrical noise (about 10µVpk).

Just for comparison: Atomic radii are in the range of 150 pm.

Examples: Mangan: 112pm, Lead: 175pm.

Displacements of 1/1000 of an atomic radius can produce well-distinguished AE signals!

Sensitivities of sensors are shown as frequency response diagrams (output voltage vs. frequency, see figure 11)

In Figure 11, the sensitivity is given in dB re 1V/µbar. So, -60 dB would mean an output voltage of 1 mVpk, if the sensor would be excited with a sinusoidal pressure of 1 µbar (peak amplitude) of the frequency at the horizontal axis (e.g. in a water bath). (-60 dB means a factor of 0.001).

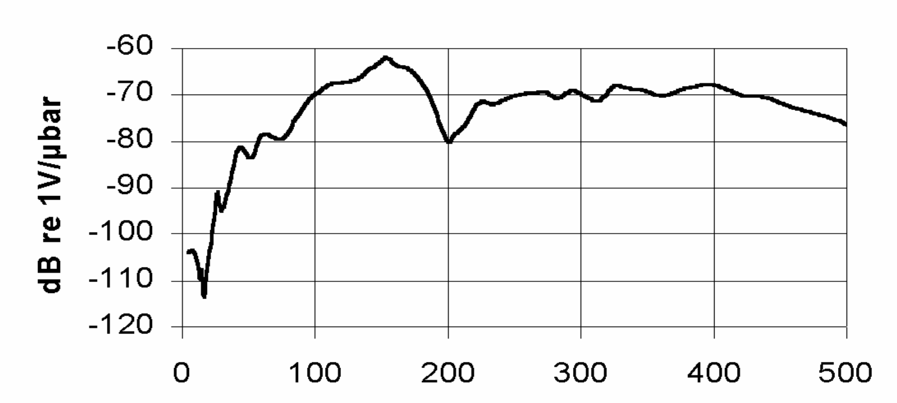

Figure 11: *Frequeny response of a resonant 150 kHz sensor (kHz)*

2.4 The dB und dB_{AE}-Scales

The dB scale is a logarithmic expression for a factor or a ratio according to the equation

$A[dB] = 20*\log(U_{out}/U_{in})$

The addition of dB values corresponds to the multiplication of their factors.

Please, calculate the following examples in mind:

a) 141,42 * 0,0005 * 1,4142. (= 0,1)

b) 43dB –66 dB + 3dB (= –20dB)

Both terms are equivalent but the addition of dB values is much easier than the multiplication of the factors.

dB	U_{out}/U_{in}
0	1,0
3	1,4142
6	2,0
10	3,1622
12	4,0
14	5,0
20	10,0
-20	0,1

Usually, the maximum amplitude of a burst is given in $\mathbf{dB_{AE}}$, so the reference voltage is 1 µV (U_{in} in the equation above). Therefore $0dB_{AE}$ corresponds to 1µV, 20dB -> 10µV, 40db -> 100µV, 60dB -> 1mV, 100dB -> 100mV.

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2.5 Attachment of the Sensors

Usually, AE sensors are attached to the test object using magnetic holders (see figure 12). With non-magnetic objects, elastic ties, tape, clamps, glue, etc are used.

When attaching sensors, please take care to avoid unwanted noise produced by loose parts, striking cables, etc.

During the whole measurement, a constant hold-down force must be ensured.

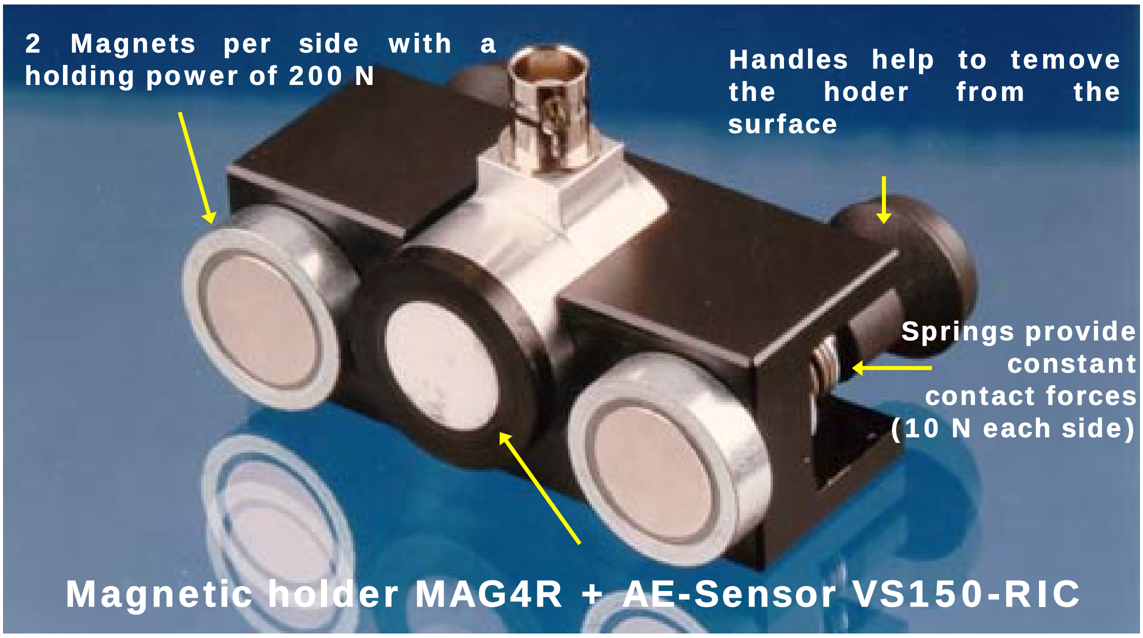

***Figure 12**:* *Magnetic holder including sensor*

2.6 The Sensor to Preamplifier cable

(Not required with sensors with integrated preamplifier)

- Connects the sensor with the preamplifier
- Shall not be longer than 1.2 m (because of capacitive load on the sensor)
- Usually very sensitive and thin (because of miniaturized sensor connectors)
- Must not be bent sharply or strained
- Never apply tensile load, especially to the connectors!
- may conduct unwanted acustc noise through the connector up to the piezo element

2.7 AE Preamplifier

The AE preamplifier can be either a separate device or is integrated into the sensor. It amplifies the AE signal and drives the cable between sensor and AE system. Important characteristics:

- Low input noise to distinguish smallest sensor signals from electronic noise
- Large dynamic range to process high amplitudes without saturation
- Large range of operating temperature for applications in the neighborhood of low temperature vessels as well as above the transition temperature from brittle to ductile behavior
- Usual voltage supply: 28 V DC via signal cable
- Optional frequency filter

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- Calibration pulse can be routed through to the sensor

2.8 Preamplifier to System Cable

- Coaxial cable, usually RG 58 C/U
- 50-Ohm BNC connectors at both ends
- May have a length of several 100 m
- Transmits AE signal, DC power supply, and calibration pulse for sensor coupling test

2.9 Frequency Filter

The frequency filter is used to eliminate unwanted frequency ranges (noise sources) and matches the measurement chain to the requirements of the application.

- 20 - 100kHz for tank bottom tests (leakage, corrosion)
- 100-300kHz for integrity testing metallically components
- Above 300kHz for reduced range (smaller distance between sensors).

Filter modules are easy to exchange. Optionally, the wanted frequency range can be selected via the software in order to match the system with the requirements in the field without changing the measurement electronics (e.g. for easy switching between tank bottom and integrity testing).

2.10 The A/D Converter

The A/D converter is used to digitize the AE signal that has passed the frequency filter. A huge measurement dynamic is required, as very strong bursts from nearby produce much higher amplitudes than weak ones from a big distance.

This shall be illustrated by figure 13. 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 and 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 13 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.

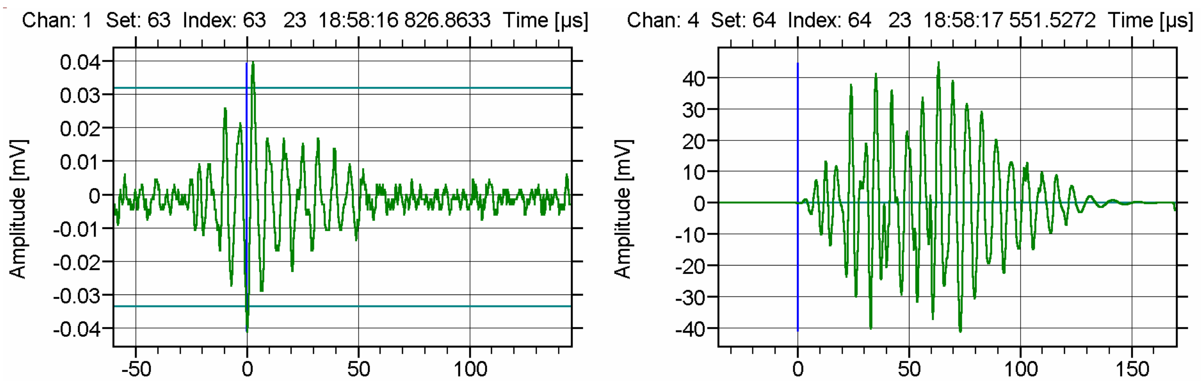

Figure 13: *AE signal dynamics - bursts with amplitudes of 40µV (left) und 40mV (right)*

The AE technique puts high demands not only on the dynamic range, but also on the measurement speed. In order to e.g. derive the maximum amplitude directly from the samples of the A/D converter (ADC) quickly and without extensive calculation processes, even the interesting signal frequencies between 100 – 300 kHz require a sample rate of 5 – 10 MHz. Figure 14 shows the section of the waveform in figure 13 (right) with the maximum amplitude at 63.2 µs. Each sample is displayed as a bullet. There are 5 bullets each µs, so, the curve was stored with a sample rate of 5 MHz. With half the sample rate, the measurement point at 63.2 µs would be missing, producing an additional measurement error of some percent. If the sample at 59.6 µs

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would be missing, the number of threshold crossings would be too low by one, as only this sample exceeds

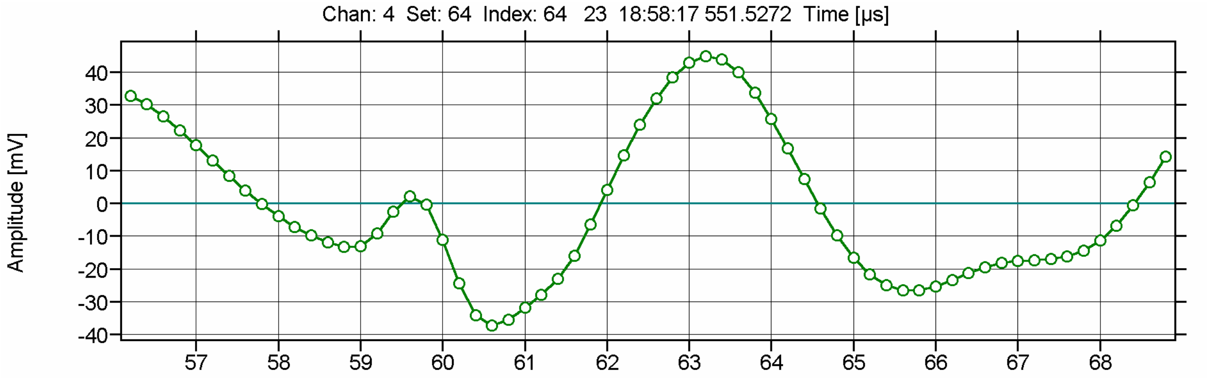

Figure 14: *Section of the maximum amplitude at 63.2 µs. Bullets correspond to measured values at a sample rate of* 5 Msamples*/second*

the positive threshold (at 32µV).

2.11 Feature Extraction

The Vallen systems AMSY4 and AMSY-5 use a continuous sampling rate of 10 MHz for the feature extraction. This implies the huge amount of 10 million measurement values per second per channel, which has to be processed in real-time. Formerly this was not possible at reasonable efforts. Today it can be realized by FPGAs (Field Programmable Gate Arrays). These special ICs have thousands of processing elements that can be linked by software. Thereby special processing setups (pipeline structures) can be designed that perform the vast number of about 420 million instructions per second (420 MIPS). That corresponds to 42 instructions per sample (at 10MHz). Result of these calculations is the feature extraction, that is providing the afore mentioned features (maximum amplitude, duration, risetime, counts, energy, and others) for every hit in each channel.

2.12 The Transient Recorder

In order to better understand the AE signals and to display the curve like in the picture above, sometimes the complete waveform is stored, even if this requires a large memory. The propagation of the wave can be extremely complex. Further research and improvements for future applications of the AE testing technique can only be done using those complete waveforms recorded by transient recorders. An enormous potential of improvement of the AE technology is already within sight today.

The transient recorder is an optional addition to the channel plug-in.

2.13 The Data Buffer

The data buffer prevents data loss in case the CPU is busy with other tasks and temporarily not ready to accept more data. Today's Windows PCs are extremely powerful but they are not made for strict real-time processing. Therefore external buffers are very important for those systems that use the advantages of standard Windows operating systems (memory of the AMSY5: about 100kHits AE, 8 MB/channel TR)

Up to this point, the number of channels working in parallel over the AE system bus is only limited by the size of the system case. Vallen-Systeme GmbH has realized AMSY4 systems with up to 144 channels, which are required if large test objects have to be monitored under load. With the new AMSY-5, the interconnection of multiple system units became even more user-friendly due to extensive self test and self configuration means.

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2.14 Personal Computer and Software

Modern AE systems use computers providing a menu-driven parameter input and system control. An online help system provides quick access to help texts explaining the use of the software.

First the result of a data acquisition is just a file containing the features of all the bursts of all the sensors as well as the external parameters, such as test pressure, temperature, and others. If the complete waveform is to be stored, another file is created. During the test the measured data is online analyzed and displayed, so the operator may immediately recognize the possible development of defects within the test object. He may then halt the load increase (e.g. pressurization at pressure tests) in order to minimize possible danger to man, environment, and the tested object.

The tasks of the PC are:

- Data acquisition and storage (all data are stored)
- Data analysis, online / offline
- Logical filtering (plausibility)
- Location calculation and clustering
- Statistics
- Display of the results (graphically and numerically)
- Self test of the system hardware
- Sensor coupling test, recording of the sensor frequency response

2.15 The Sensor Coupling Test (also referred to as *auto-calibration*)

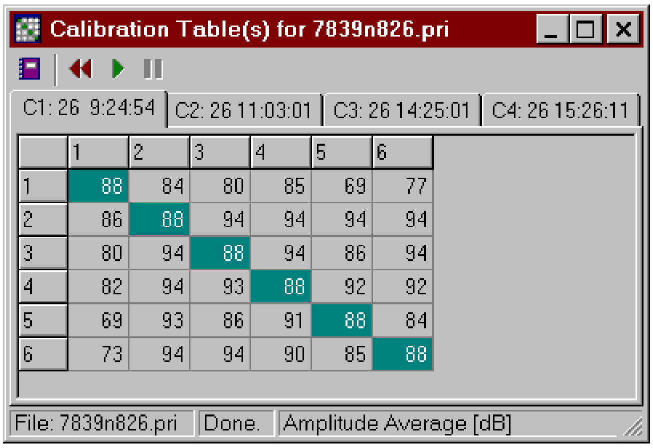
Using this function the coupling of the sensors can be checked automatically.

One channel transmits an electrical test pulse to the connected sensor. This sensor emits a mechanical wave, which is detected by the neighboring sensors. After 3 test pulses, the next sensor becomes the pulse emitter. The plausibility of the received amplitude allows to draw conclusions on the quality of the coupling.

The table on the right shows a sensor coupling test with 6 channels.

Sample reading: Row 6, column 1: value 73dB

The value of 73dB means that the wave emitted by channel six had 73 dB amplitude when arriving at channel 1.



	1	2	3	4	5	6
1	88	84	80	85	69	77
2	86	88	94	94	94	94
3	80	94	88	94	86	94
4	82	94	93	88	92	92
5	69	93	86	91	88	84
6	73	94	94	90	85	88

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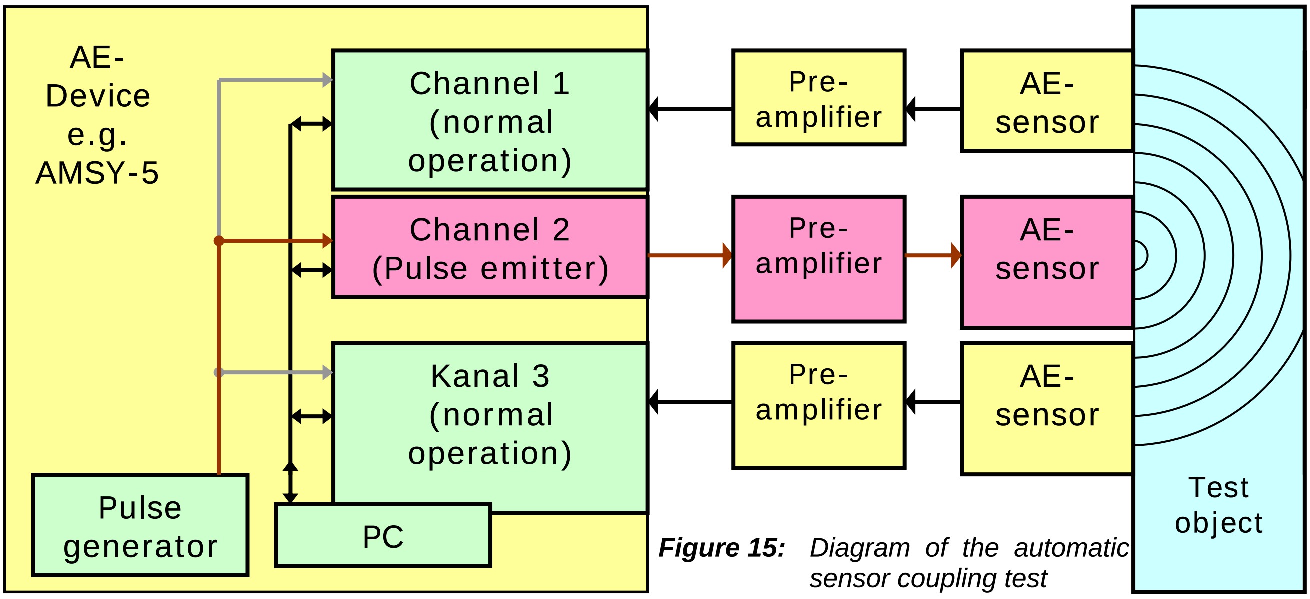

Figure 15: *Diagram of the automatic sensor coupling test*

The automatic coupling test is performed before and after the test in order to prove a constant quality of the coupling.

2.16 Front View of an AE System

Figure 16 shows the front view of a standard modular 15 channel AE system (model AMSY4 by Vallen Systeme GmbH) used for AE testing by well reputated test institutes (e.g. TÜV Austria, TÜV Rheinland, TÜV Süddeutschland, Delta-Test, and many more).

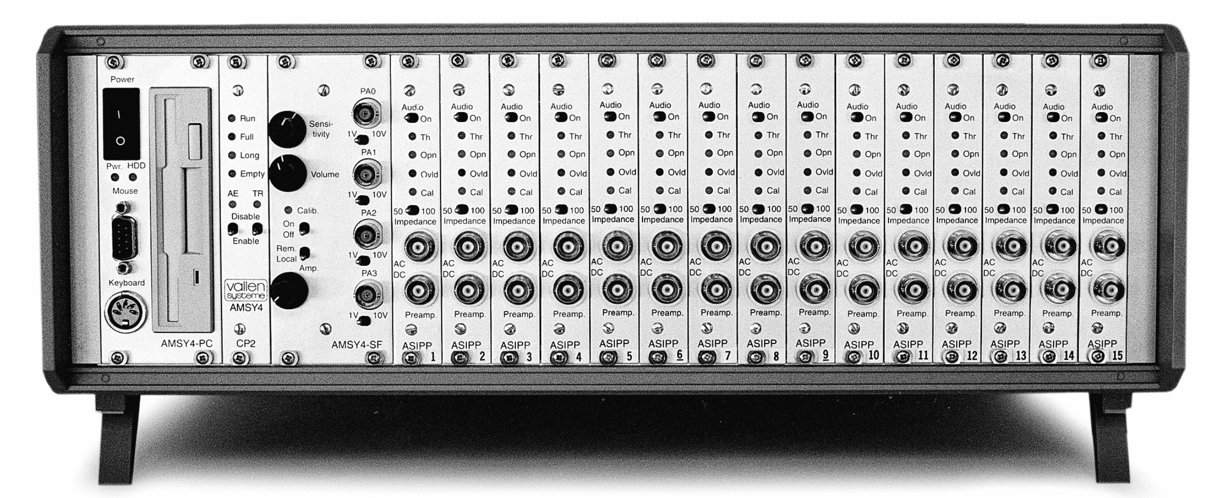

Figure 16: *AMSY4 System with 15 AE channel plug-in modules (ASIPPs)*

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3 Location Calculation and Clustering

3.1 Location Calculation Based on Time Differences

The determination of the source location of each event is an essential element of AE testing. The distance difference between a source (defect) and different sensors are equal to *Arrival Time Difference * Sound Velocity*. Location calculation is based on the evaluation of the arrival time differences of the AE signal propagating from its source to different sensors as illustrated in the two-dimensional example shown in Figure 17. An AE wave is propagating in concentric circles from its source and arrives at different sensors with certain delays. The delay is proportional to the distance between the sensor and the source. In this example the wave first reaches sensor 1, then 4, 2 and, at last, sensor 3.

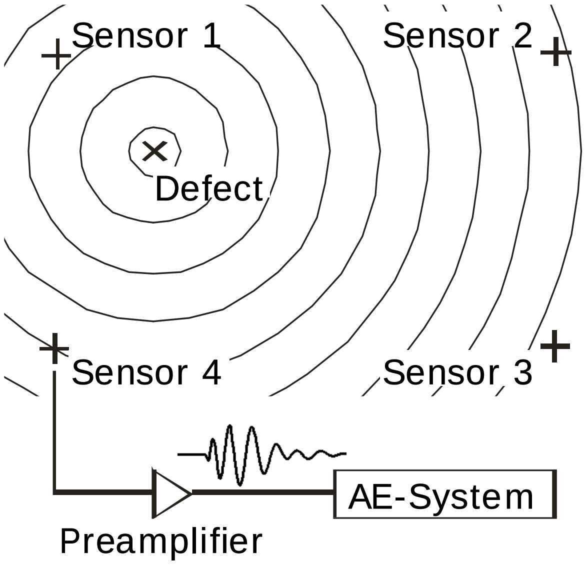

Figure 17: *The principle of localization*

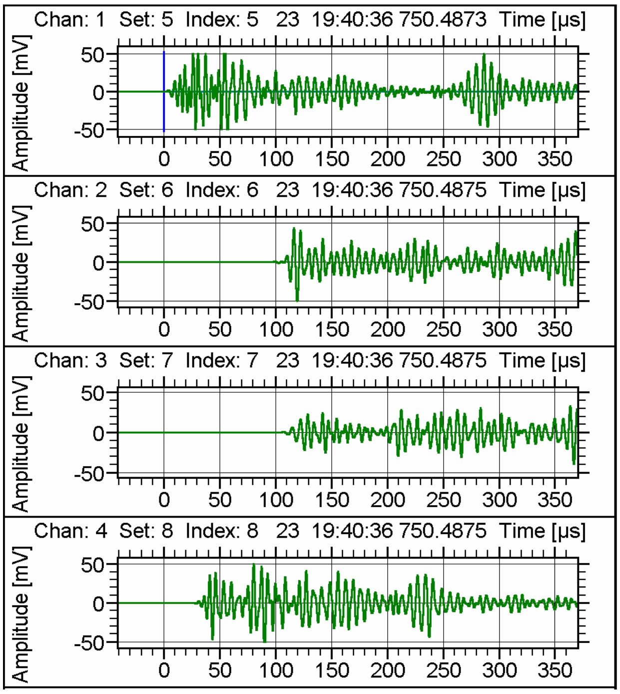

Figure 18: *Sensor signals*

In figure 18 the waveforms of a breaking pencil lead on an acrylic glass plate with four sensors, configured similar to figure 17, are displayed. The zero of the time axis marks the arrival time at the sensor 1, that was hit first in this example. The arrival time differences between channel 1 and the channels 2, 3, and 4 can be read at the time axes of the waveform diagrams.

All points having a constant difference between their distances to two fixed points form a hyperbola. Figure 19 shows three hyperbolae, each representing all points with the calculated distance difference to two sensors. At the point of intersection of the three hyperbolae, the three distance differences are equivalent to the measured time differences. So, this is the wanted source position. As can be seen in this example, the arrival time at three sensors is required to find the point of intersection. If an AE event only arrives at two sensors, there is only one couple of sensors and, thus, only one hyperbola, which is not sufficient for this method to calculate the planar location. Hyperbola diagrams (like in figure 19) are mainly used to check the plausibility of certain selected location results. Mostly, the calculation is based on an inverse method, which, in addition to the location results, provides a measure of the reliability of the location calculation, if more than three sensors have been hit by the event.

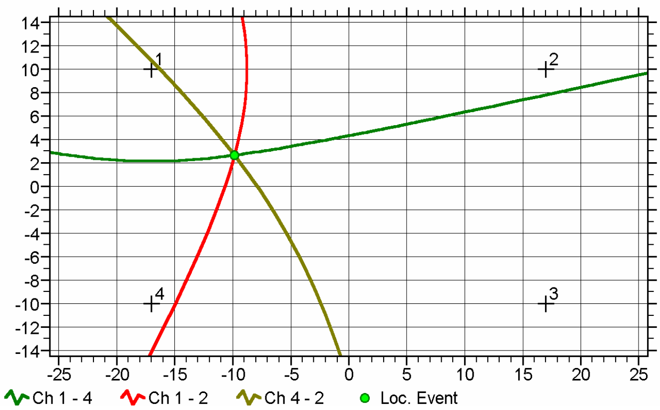

Figure 19: *Hyperbola intersection with 3 hit sensors*

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Usually, the results of a location calculation are plotted in a point diagram without the hyperbolae, but including the positions of the sensors, as shown in figure 20. The data of figure 20 have been recorded during the compression of a 5 cm thick glass foam plate producing a huge number of events. Accordingly, it is quite difficult to find locations in the diagram with highest location density, as we can't see how many points are overlaying. Usually, the AE technology uses the so-called ***clustering*** in order to clearly mark off those areas of high location density.

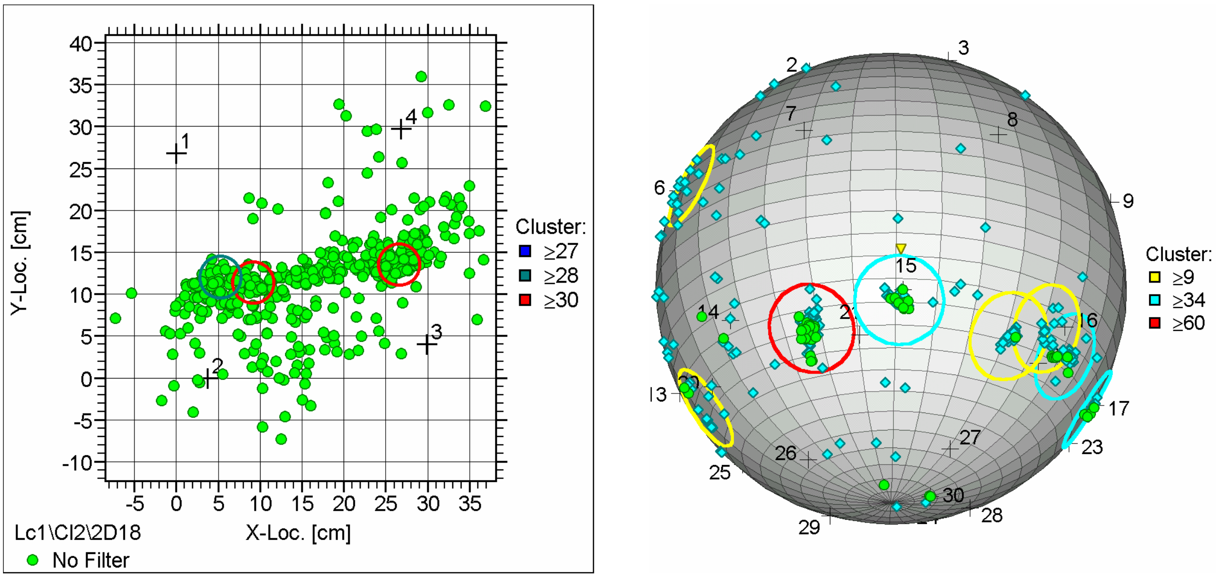

Figure 20: *Location and clustering charts*

3.2 Clustering

Clustering is a mathematical method used to determine the point density within a certain area, marking those areas of high point density by colored rectangles or circles. The left diagram of figure 20 shows three clusters, so, three areas of high point density where found. The clusters are marked by colored circles, the color indicating the number of elements within the cluster. In addition to the planar location, other location algorithms are required, such as the location on a sphere surface (spherical location calculation) providing a 3-dimensional rotating display of the sphere shown on the right of figure 20. Even here, clustering is required and possible. Spherical liquid gas and natural gas tanks are important test objects where the application of AE testing could prove its capability in many cases.

The display of results as shown in figure 21 is of special interest with respect to location clusters. The horizontal axis shows the cluster ID. The vertical axis on the left scales the amplitude points, and the vertical axis on the right displays the number of events per cluster indicated by the stepped line. This diagram clearly shows the tester even during the test whether location clusters with high numbers of events and relevant

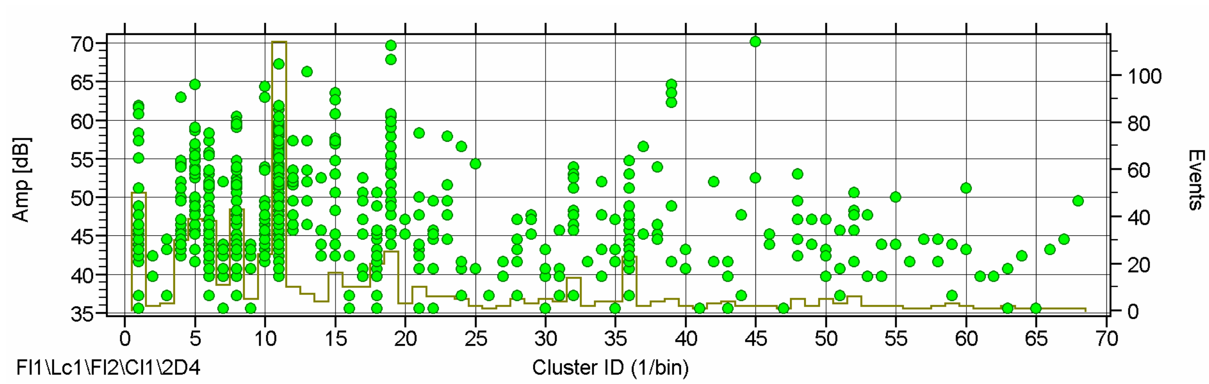

Figure 21: *Amplitude and number of event vs. the cluster ID*

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amplitudes are forming. He can see immediately whether new, located defects develop. Looking at the diagram above, cluster no. 11 contains about 105 events (see right scale) with amplitudes of 39 to 67 dB (see left scale).

Figure 22 shows a sample analysis screen as the tester sees it during the test or during post test analysis. Diagrams, that require an explanation, have been mentioned above. The small information boxes appear as soon as one of the points (a certain AE event) has been selected by a double click, which allows to easily refer to any event within various types of display

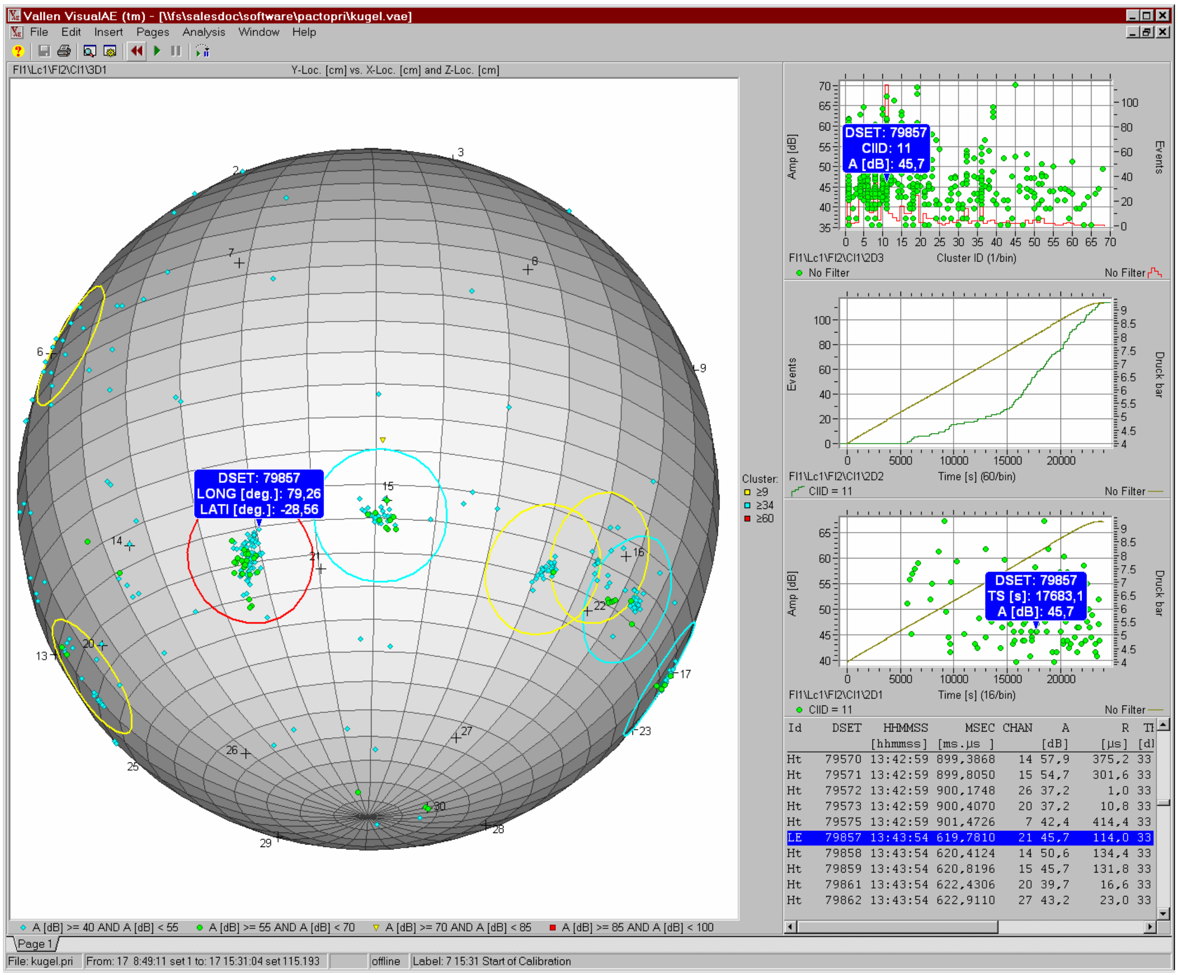

Figure 22: *Sample screen displaying various diagrams and a listing*

3.3 Location Errors

Compared to the early days of AE testing, nowadays an excellent location technique is available to the AE tester. Anyway there is still room for improvements to be developed. Today, the AE tester himself has to take care of influences causing location errors and rate them in a correct way.

Some of the influences on the location accuracy are:

- A different wave mode than the assumed one determines the arrival time
- A wave takes a different propagation path than assumed by the algorithm
- Multiple waves overlap at the sensor
- Sources emit signals in such a quick succession, that there is not enough time for the signals in the structure to decay, therefore do not represent a "new" hit.

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One of the problems is, that from the AE signal one can't know whether it was produced by a real defect and, if so, how big e.g. the crack growth was. One has to build up know-how by investigating the emission behavior of materials by tensile tests in the laboratory. Doing so, one has to consider, that e.g. the propagating conditions for mechanical waves in real test objects and small samples are different. All these aspects may make the un-experienced feel uncertain about the AE technology. But the theoretical and practical knowledge of the AE behavior of materials and structures increases steadily and will soon be taught at universities and made available to everyone in technical books.

Figure 23 illustrates a typical cause for location errors. The upper waveform (channel 2) has exceeded the threshold (the 0.1 mV lines) for the first time by a wave mode (t = 0), which produces the highest amplitude at 25 µs. This wave mode propagates with about 3.2 m/ms. Channel 3 (lower waveform) has received a stronger signal (the sensor of channel 3 was a little closer to the source). Here, the threshold was first crossed (t = 0) by a 'predecessor' signal. The predecessor is a faster wave mode propagating with a speed of about 5 m/ms. The time of the first threshold crossing of the wave mode propagating with 3.2 m/ms at channel 3 is found at about 140 µs. So, the arrival time of the lower waveform is 140 µs too early, if the location algorithm uses a speed of 3.2 m/ms. Hence the distance difference between the source and the channels 2 and 3 is calculated by 0.5 m (0.14 ms * 3.2 m/ms) too small, producing a considerable location error. As the example of these two waveforms shows, the determination of the arrival time by the first threshold crossing is quite problematic.

We have to be especially aware of location errors if there is inhomogeneous wave propagation, which e.g. is the case close to manholes, nozzles, etc. Materials with anisotropic wave propagation do not allow for precise location.

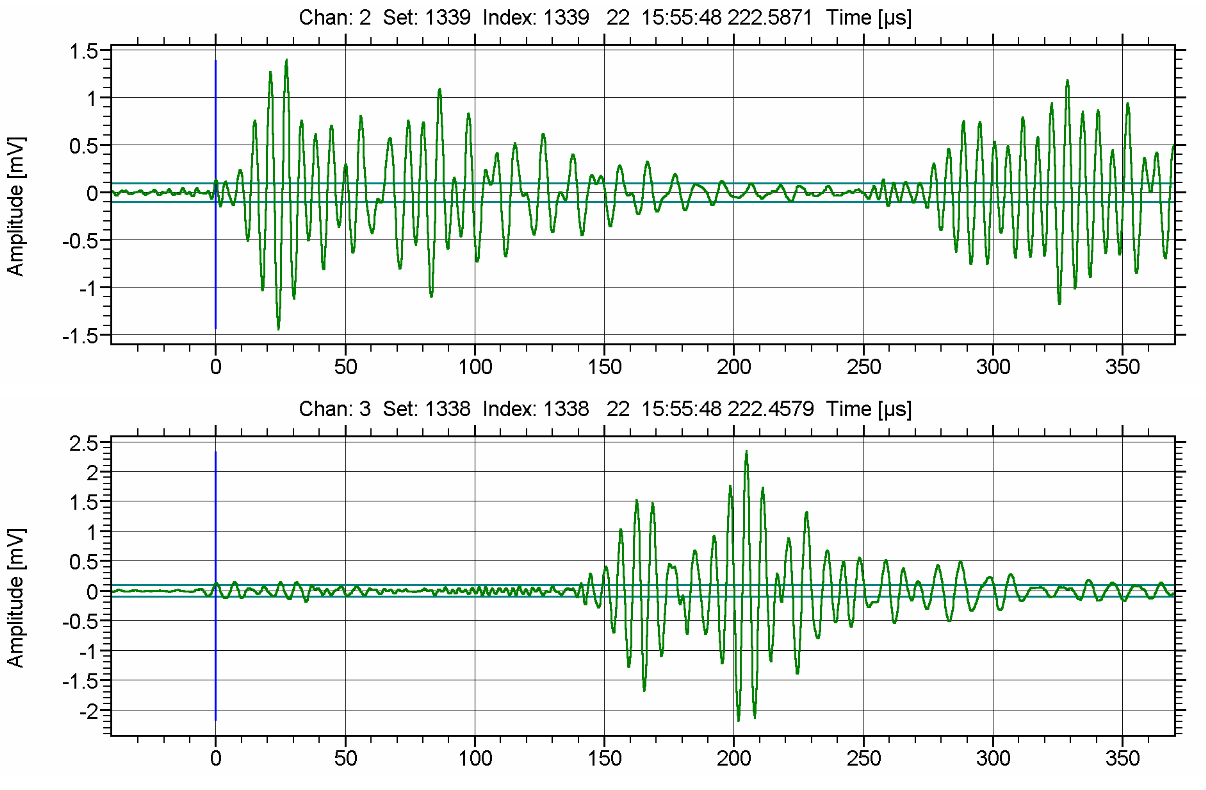

Figure 23: *Location error caused by the acquisiution being triggered by different wave modes. Top: a0, bottom s0*

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4 Visualization of Measurement Results

One of the main tasks of an AE system software is the clear and well-structured display of the AE data.

The display types of AE data are as follows:

- Numerical display
- Cumulative or differential diagrams, e.g. total number of events, total number of bursts, total energy vs. time or pressure
- Pressure vs. time
- Distribution of amplitudes or other parameters.
- Location diagrams including a picture of the test object and a cluster display (see section **Location Calculation and Clustering**)
- Waveform diagrams in time or frequency domain (see section **Location Errors**)

4.1 Numerical Display

The advantage of data listings is the fact that each row of a listing actually contains a complete set of full precision feature data of a single burst.

Usually, listings are used to print the results of calibration measurements as below:

```
Id     DSET   HHMMSS      MSEC CHAN    DT1X         X         Y      DstX     A  CNTS      E        R         D      TRAI
            [hhmmss] [ms.µs ]          [µs]      [cm]      [cm]      [cm]  [dB]         [eu]     [µs]      [µs]
La Label  6: 15:15 -4,40
LE      552 15:15:06 200,3713   1                 -3,60     41,16     31,37 88,1  4712  20E03     48,8  52032,0       61
Ht      553 15:15:06 200,5242   2   152,9                            110,87 86,6  5094  24E03    158,4  56115,2       62
Ht      554 15:15:06 200,6138   4   242,5                            157,47 82,1  5134  27E03    479,2  53043,2       63
LE      579 15:15:10 765,2106   1                 -3,58     41,41     31,61 88,1  4595  18E03     49,4  49740,8       67
Ht      580 15:15:10 765,3632   2   152,6                            110,96 84,8  5175  22E03    158,6  62899,2       68
Ht      582 15:15:10 765,4522   4   241,6                            157,24 80,2  5022  24E03    475,6  51481,6       69
LE      621 15:15:15 389,6823   1                 -3,19     41,12     31,28 89,3  4792  21E03     50,4  52505,6       79
Ht      622 15:15:15 389,8361   2   153,8                            111,25 86,6  5215  25E03    158,6  57190,4       80
Ht      623 15:15:15 389,9253   4   243,0                            157,64 82,1  5287  28E03    668,4  59494,4       81
La Label  7: 15:15 -4,50
LE      713 15:16:29 939,9533   1                 -3,60     51,77     41,92 89,3  5192  25E03     62,6  54630,4       84
Ht      714 15:16:29 940,0925   2   139,2                            114,31 87,4  5549  30E03    160,6  58444,8       85
Ht      715 15:16:29 940,1563   4   203,0                            147,48 85,9  5604  35E03    717,6  56934,4       86
LE      738 15:16:34  77,3212   1                 -3,96     51,01     41,20 86,3  4498  17E03     62,2  47872,0       90
Ht      739 15:16:34  77,4606   2   139,4                            113,69 85,1  4907  20E03    160,2  52684,8       91
Ht      740 15:16:34  77,5267   4   205,5                            148,06 78,7  4904  23E03    497,6  53171,2       92
LE      762 15:16:38 344,3068   1                 -3,63     51,22     41,38 87,0  4712  19E03     62,6  49996,8       94
Ht      763 15:16:38 344,4466   2   139,8                            114,08 85,5  5100  23E03    160,0  55731,2       95
Ht      764 15:16:38 344,5118   4   205,0                            147,98 82,1  5189  27E03    715,8  56268,8       96
La Label  8: 15:16 -4,60
```

Each line presents the data of a single burst and the location results are assigned to those channels, which have been hit first. So, the column **HHMMSS MSEC** contains the time for each burst by hour, minute, second, and millisecond with a resolution of 0.1 µs. The next column (to the right) displays the channel number, followed by the time difference with respect to the first hit channel of the event. Next the location results **X** and **Y**, the distance between sensor and source **DstX,** then the parameters **A** (maximum

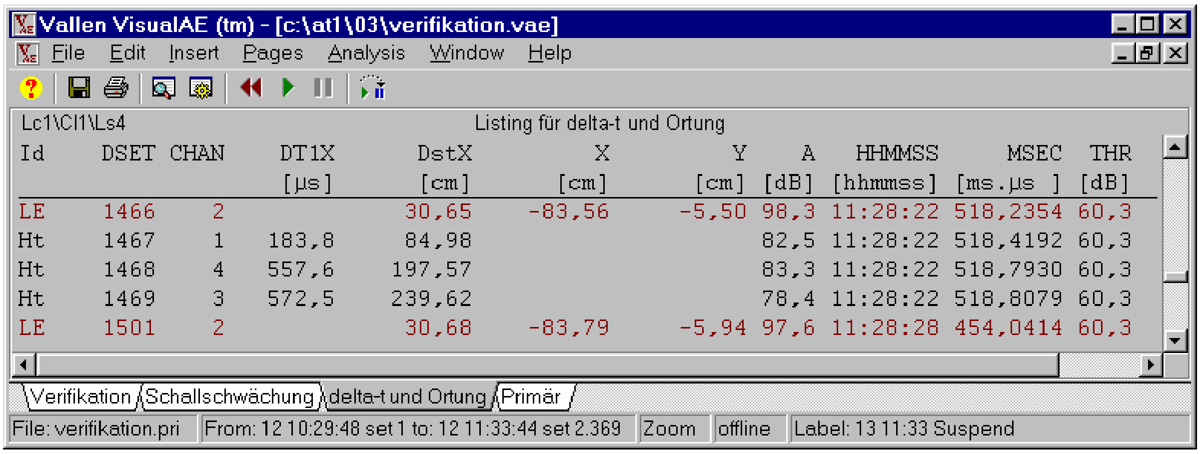

Figure 24: *Screen shot of a numerical result listing*

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amplitude), **CNTS** (number of threshold crossings), **E** (energy), **R** (risetime), **D** (duration), and **TRAI** (transient recorder index) indicating the associated waveform.

The inserted **Label** lines contain comments entered by the operator during the data acquisition. In the example above, the operator entered the coordinates for a pencil lead break with three breaks per position. So, the **X** and **Y** values should be identical to the values in the **Label** line. Comparing the values we find location errors between 4 and 15 mm.

A real disadvantage of listings is the fact that only a limited amount of data can be viewed at a time. The screen provides a vertical and a horizontal scrollbar used to move the display window into any position within the listing, so any part of the listing can be viewed quickly. Additionally, a double-click on any point of the point diagram automatically moves the listing window to the associated line and vice versa. This allows one to quickly correlate a line of the listing with the graphical data output, such as location results, etc.

4.2 Cumulative and Differential Diagrams – a Sample Evaluation

Both diagrams below show the same AE data. Figure 25 displays the disproportionately strong increase of the total number of events vs. time. During the first 12,000 seconds, about 100 events were located, during the second 12,000 seconds about 500. The diagram also displays the linear pressure increase from 4 bar to 9 bar (see scale on the right).

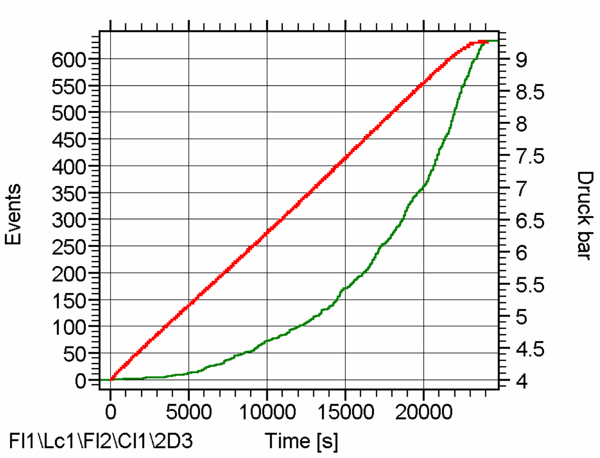

Figure 25: *Cumulative diagram of the total number of events vs. time incl. superposed curve of linearly increasing pressure*

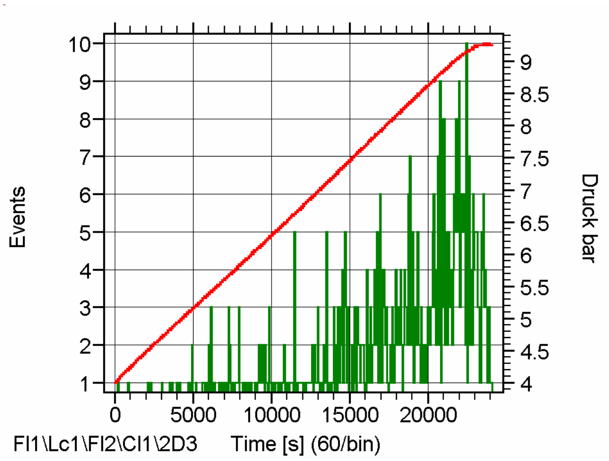

Figure 26: *Differential plot of the event rate vs. time with intervals of 60 s (with superposed pressure curve)*

In figure 26 pressure and event rate are plotted vs. time with a resolution of 60s (as specified in the legend by **60/bin**). Towards the end of the pressure increase, there is a time interval with a maximum of 10 located events per minute. The operator has to monitor such information, based on defined stop criteria (usually put in writing). I.e. he has to stop the pressure loading process in case a stop criterion is fulfilled, or has even to decrease the pressure, if the event rate keeps rising.

On the screen, the curves have different colors and can easily be associated with the corresponding axes.

In contrary to the pressure, the event curve shows a disproportionately strong increase, which indicates growing defects within the structure.

In some cases, the pressure loading has to include periods of constant pressure (load hold). During these periods, the AE is expected to fade. Figures 27 and 28 are displaying data of an artificially damaged test object. The amplitudes occurring during the phases of comparatively low load and, especially, during the pressure-hold phases most certainly indicate a defect.

Once more it should be mentioned that "certainty" in the interpretation of AE-signals only develops by certain experience e.g. with the knowledge of the differences between a "good" sample and a defective one.

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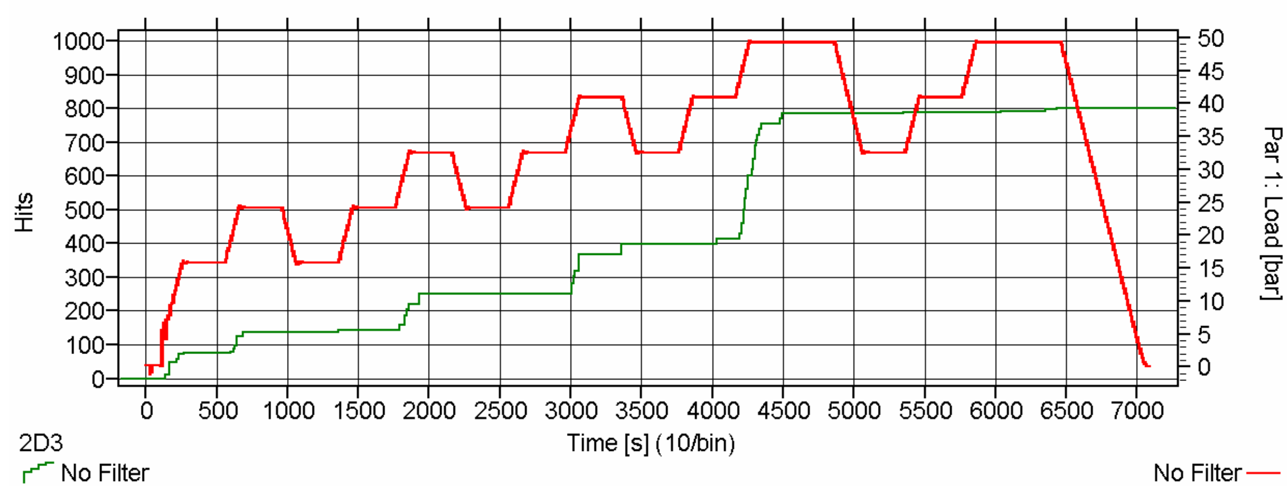

Figure 27: *Cumulative diagram of the total number of hits (activity) vs. time with superposed pressure curve with periods of constant and decreasing pressure*

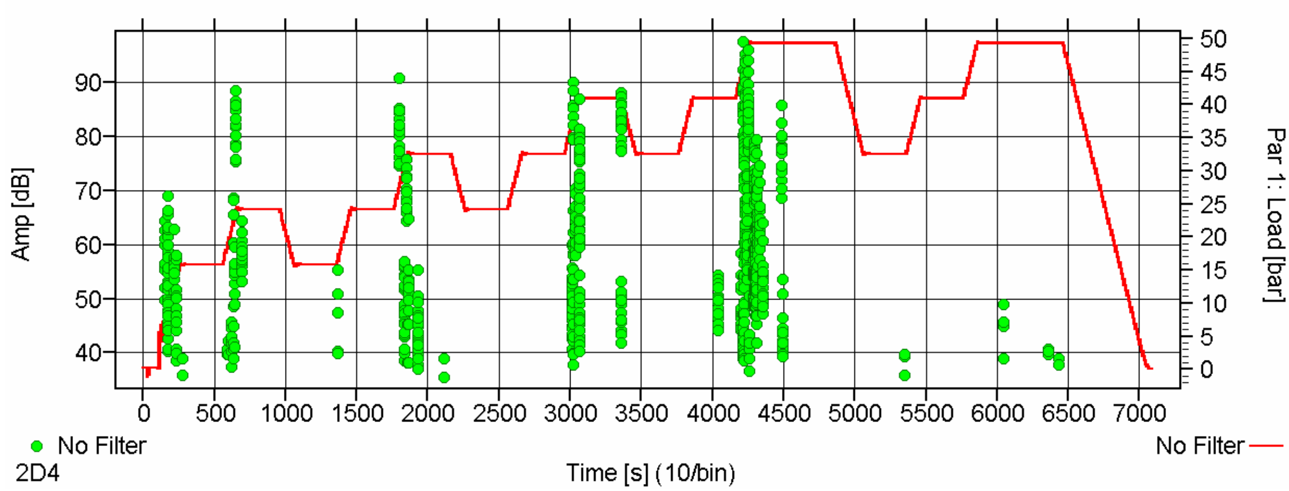

Figure 28: *Point diagram of the amplitude (intensity) vs. time with superposed pressure curve showing periods of constant and decreasing pressure*

Various filters can be applied to the diagrams, that e.g. only the events of a single source (a single cluster or a group of clusters) are plotted. The result is directly used for the characterization of the corresponding source with respect to the applicable criteria.

Typical source characteristics are:

- **Not relevant**, if e.g. the hit rate does not increase with load or the cause of the activity is known to be irrelevant.
- **To be tested using conventional NDT**, if the origin of the source cannot be found, or
- **Critically active**, if the hit-rate increases with load or exceeds a certain limit.

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4.2.1 Pressure vs. Time

The figures 25 – 28 all contain an additional line showing the pressure vs. time. As mentioned above, the common display of AE activity and pressure increase or pressure hold is an important characterization feature.

4.3 The Amplitude Distribution, a Sample Evaluation

Figures 29 and 30 show plots of amplitude distributions. The cumulative plot in Figure 29 shows how many hits have reached or exceeded the amplitude as specified on the horizontal axis. At e.g. A = 50 dB, the curve indicates a little more than 200 hits (**hits** having the same meaning as **bursts**), i.e. there are about 210 bursts with a maximum amplitude of 50 dB or more. The lesser the slope of the amplitude distribution towards higher amplitudes, the more critical the test object has to be rated. A written procedure could e.g. contain stop criteria, according to which the pressure loading has to be stopped in case xx hits with a maximum amplitude of yy dB or higher have occurred. The diagram clearly shows if such a criterion has been exceeded.

The differential plot on the right (Figure 30) shows how many hits (bursts) have a certain maximum amplitude. E.g. a measurement that has been disturbed by background noise shows a certain increase towards lower amplitudes, which is not the case in this example. Several maximums within the amplitude range indicate, that the diagram contains data of different sources. If necessary, the operator can apply a filter to have the diagram display the data of one source only.

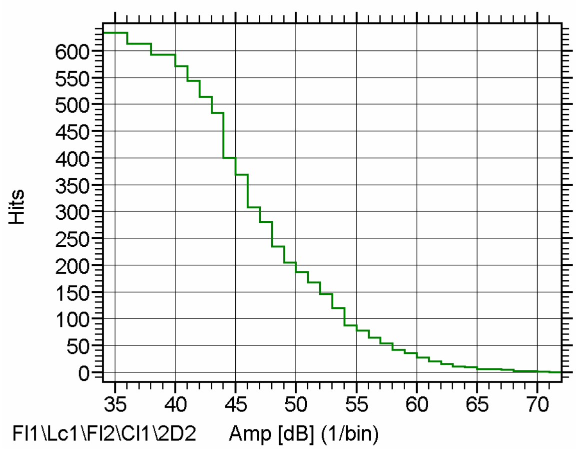

Figure 29: *Amplitude distribution, cumulative down*

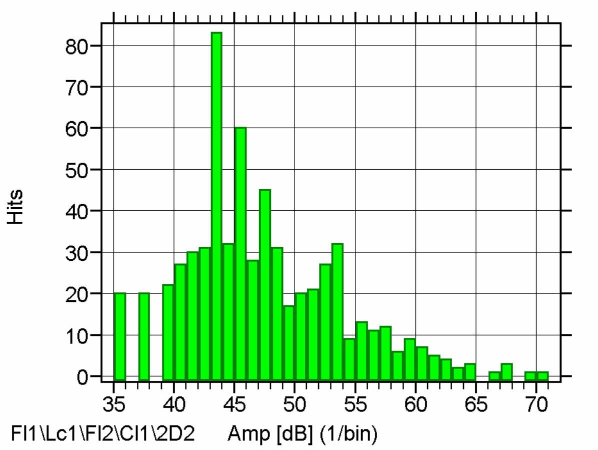

Figure 30: *Amplitude distribution, differential*

Distribution diagrams of the type shown above can also make sense with other results such as energy, number of threshold crossings, etc.

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4.4 Point Diagrams Showing Quantity vs. Time or Quantity vs. Quantity

The diagram in figure 31 displays a point (circle) for every event, indicating both its amplitude and time. In the diagram of figure 32, each point marks the amplitude and the duration of an event.

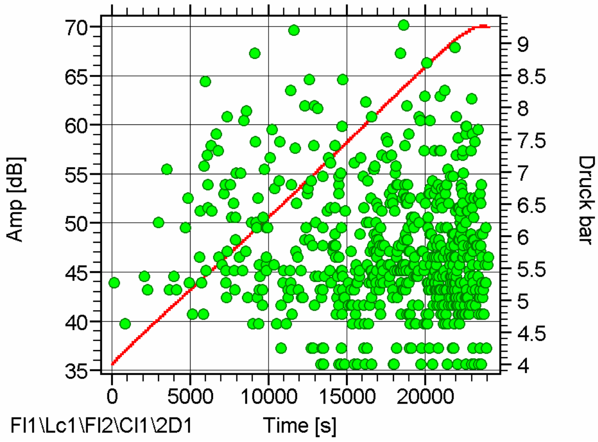

Figure 31: *Point diagram of the amplitude vs. time*

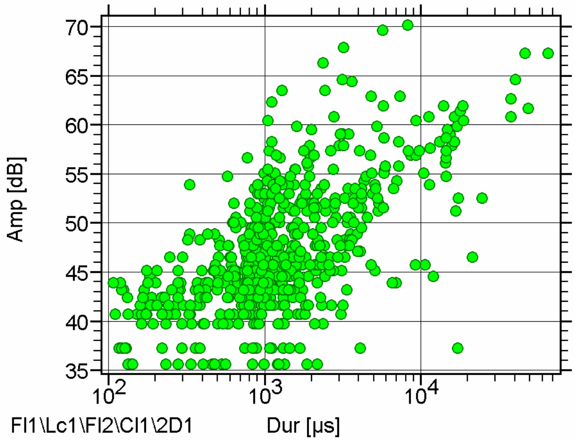

Figure 32: *Point diagram of the amplitude vs. duration*

Point diagrams give a good overview of which single values occurred. In the figures 31 and 32, each event is represented by a point. In both charts, single hits can only be identified in the extreme ranges without using additional tools. E.g. in each of both diagrams there is only one hit with an amplitude of slightly above 70 dB, so it must be the same hit in both charts. Often it is desirable to identify a single hit in various diagrams. This is one of the features of the software of Vallen-Systeme: A double-click on a point in any diagram highlights this hit in all other point diagrams with a small information window.

4.5 Location Charts Including an Image of the Test Object and a Cluster Chart

Location charts have been presented in Section **Location Calculation and Clustering** (see figure 20).

4.6 Diagrams of Waveforms vs. Time and Frequency

Diagrams of waveforms vs. time have been shown above. The following charts show a combination of time- and frequency-related charts. The diagram on the right displays the frequence spectrum of the signal section that has been framed in the chart on the left. The operator can easily move or resize the frame in order to find out, in which sections of the time-related diagram the frequency components change. The experienced AE-tester uses the frequency spectrum (right) as an indicator of the source mechanism (useful signal or noise) or the wave mode of the section inside the frame.

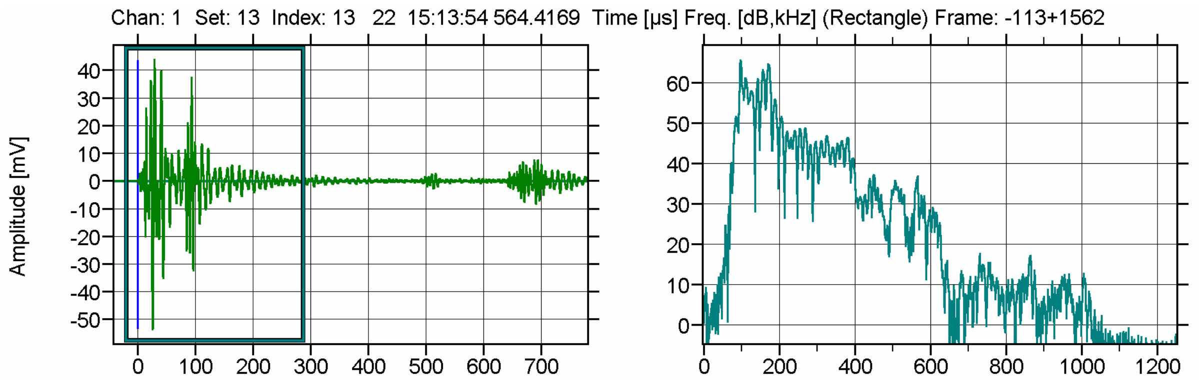

Figure 33: *Waveforms in time- (left) and frequency (right) domain*

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This kind of frequency analysis is just the lowest level of it. Presently pattern recognition is going to be developed as far, that it will be able to extrapolate the depth of the AE source from the frequency-time-correlation of the AE-signals.

5 Characterization of AE Sources

Some of the characterization criteria have already been explained in connection with some of the charts above. Here is a summary of important characterization criteria:

5.1 The Kaiser-Effect

Dr. Joseph Kaiser's dissertation (about. 1950) at the Institute for Metallurgy at the Technical University Munich was named: „Examination about the occurrence of sound at tensile tests". At this dissertation Dr. Kaiser indicates irreversible processes during plastic deformation under strain which can be shown by using a piezoelectric crystal. Due to his dissertation and continuing research until his decease 1958, the Technical University Munich is known as the origin of the AE-Technology. A friend and colleague of Dr. Kaiser, the Munich Professor Hans Maria Tensi, called the phenomenon Irreversibility of the AE-behavior in materials the "Kaiser Effect".

Nowadays the expression "Kaiser Effect" has a wider meaning. According to EN1330-9-2000 it describes the "absence of detectable acoustic emission until the previous maximum applied load has been exceeded".

If a specimen is loaded heavily for the first time, the stress generated by the external load is added to the internal stresses, e.g. originating from the production process. During this phase, irreversible relaxation and settlement processes may take place, stabilizing the material. These processes produce AE. If now the specimen is relieved from stress and then stressed again, acoustic emissions will occur not before the maximum previous stress is exceeded.

In steel this effect fades out after about one year. For this reason AE-testing of metal vessels should not be repeated after less than one year, to be sure that weak spots emit AE during a new test pressurization.

Because AE-testing should not be repeated after a short delay, a sufficient number of sensors and AE channels, depending on the size of the test object, must be available. It is neither allowed to repeat the pressurization with another sensor placement, nor to perform a trial pressurization prior to the AE-test.

If a structure, after relief and during a second loading, emits AE before the maximum of the first loading is reached, thereby violating the Kaiser-Effect, this may indicate a defect. On the other hand, sources of interference have always to be taken into account. So, usually, a final judgement can only be given after the pressure increase is stopped and the AE has been monitored during the pressure-hold phase, during which the AE activity should calm down. Sources which cannot be definitely identified, are not acceptable within the pressure-hold phase. So, if there is unexplainable AE activity during the pressure-hold phase, the pressure must be decreased and the AE test aborted.

5.2 Clustering

Clustering always indicates a source, which repeatedly emits acoustic signals. Occasionally, these sources are easily to be identified (e.g. abrasion marks, annexes, etc.). If the source cannot be identified, a real defect must be assumed. Therefore paying attention to the activity and intensity of a cluster (figure 21) is important.

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5.3 Intensity (Mean Values of Amplitudes or Energy)

Intensity parameters (amplitude, energy) increasing with external load indicate a defect.

5.4 Increase of Activity

A defect is also indicated by a disproportionate increase of activity under load (number of hits or located events).

5.5 High Amplitudes, also Single Signals (Big Bang, Forced Rupture)

Depending on the test object (e.g. juggling joints at liquid vessels) even a few single signals of high amplitudes may refer to severe defects requiring an immediate pressure decrease. With this type of test objects it is very important to calibrate the measured amplitude with respect to the distance, i.e. to take into account the attenuation of the acoustic signal depending on the distance to the sensor.

5.6 Activity during Phases of Constant Pressure

This type of activity may be a sign of a beginning or continuous destruction process.

5.7 Amplitude Distribution

A flat decay of the cumulative amplitude distribution means, that a considerably high number of high amplitudes have been detected, which may be caused by defects.

5.8 Indications of Sources of Interference

The existence of sources of interference during an AE test may be acceptable if the signals produced by these sources can be distinguished from potential defect signals.

Usually, the following situations are caused by sources of interference:

- Many channels being hit simultaneously (interference by electrical peaks)
- Many hits showing very short durations (< 5 µs) and low amplitudes (threshold too close to the background noise level); increase threshold
- Hits of long durations and low amplitudes (abrasion noise or threshold close to noise level); increase threshold
- Activity not decreasing with increasing pressure
- Detection of non-ending hits on one or more channels, e.g. due to continuous AE from a leakage

6 Advantages and Limitations of AE Exemplified by the Water and Gas Pressure Tests

6.1 Advantages

Numerous test objects ranging from spherical natural or liquid gas tanks to petrochemical reactors have been tested successfully during the last years using the AE testing method. AE testing is done to complement the water pressure test (hydro test) and, increasingly, also the gas pressure test (pneumatic test).

AE monitoring of a pneumatic test can be used to ensure a safe test. In addition to its use as a NDT method, AE testing can be used as early-warning system for developing and/or growing defects. Thereby a test can be stopped before a critical situation occurs.

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Using an AE controlled pneumatic test, the following drawbacks of the hydro test can be avoided:

- The pressure systems and their supports must be sufficiently dimensioned for the water loading (weight), which in some cases means a considerable over-dimensioning. So, often absurd solutions are required, such as replacing a simple support by a support ring etc.
- Long downtimes are required, caused by the removal of the working medium as well as the cleaning of the vessel before the water delivery. Also, releasing rest gases may be hazardous to the environment.
- The humidity remaining in the vessel after draining may cause various effects ranging from corrosion via hydrogen-induced-crack (HIC) formation to a complete system breakdown. The drying processes used to remove the humidity are, if feasible at all, quite expensive and, thus, applied rather seldom.
- The water used for pressurizing the object gets polluted and must be thoroughly purified before being released into the environment.
- During the testing of chemical reactors, the catalysts become unusable. Exchanging them causes enormous extra expenses and environmental stress.
- The hydro test only provides the information **no blowing-up**, **no leakage,** and **no noticeable deformation**. It does not provide any indication of whether a defect has been initiated or expanded during the test, which may cause a later failure of the vessel.

In addition to the disadvantages of the hydro test mentioned above, the pressurization using the storage medium (gas or liquid) provides other advantages:

- In many cases the pressure system can be tested almost under standard operating conditions, e.g. with low-temperature applications, the material will be tested in the appropriate temperature range. With warm reactors, the test temperature can be kept above the transition temperature between ductile and brittle behavior.
- AE testing can also detect corrosion, so in most cases there is no reason for an internal inspection of the pressure system and it can be taken into operation again without being opened.

More advantages compared to other NDT methods arise from the basic principles of AE testing:

- It monitors the dynamic reaction of the test object upon the applied load passively and without intervention.
- It often allows detecting sources over a distance of several meters to the sensor.
- It allows 100% pressurized wall monitoring.
- It allows real-time monitoring of the growth of known and unknown defects at a given load, even remotely by data transmission e.g. by using a modem/internet.
- It can monitor a structure under operating conditions.

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6.2 Limitations

Despite all the advantages of AE testing, we have to clearly point out, that it cannot be applied always and everywhere.

- Defects, which are neither growing nor moving do not produce AE and, thus, cannot be detected.
- According to the Kaiser-Effect, only those defects are detected without exceeding the highest preceding load, which are already active at the actual load level and are endangering the component anyway. Only by increasing the load above the previous maximum load level defects can be found, which do not grow at standard load.
- Evaluation criteria do not exist in form of commonly accessible data, i.e. the rating of AE-results is set firmly to the knowledge and experience of the service provider.
- AE testing is sensitive to process noise exceeding the detection threshold. In case the process noise cannot be stopped, the detection threshold has to be increased, which requires smaller distances between the sensors and, accordingly, more sensors and channels. Above a certain noise level, AE testing is no longer efficient.

The provider of AE testing has to collect the required information about the structure to be tested from the owner/operator during test preparation. E.g. he has to know the geometry of the object (sphere, cylinder, etc.) and which material it is made of. Operating pressure and temperature as well as other loads, especially measure and duration of the highest load during the last year have also to be known. Some of the AE testing organizations also ask for information on the manufacturing process, the yield point, tensile strength, toughness, or yield point at elevated temperature. Also, he needs information about pressure application, the possibilities of pressure reduction in case of danger, the accessibility of the object with respect to sensor application, possible sources of interference, etc. The European standard EN13554 Non-Destructive Testing – AE - General Principles provides some assistance in setting up checklists. By systematically collecting detailed information the test institutes increase their know-how in order to refine the internally developed characterization criteria.

6.3 The Spherical Liquid Gas Tank as an Example for the Test Procedure

The test procedure has to be put down in writing as part of a testing instruction and will include the following basic steps:

- Comprehensive visual check to find out whether all essential facts have been collected and no piece of information was missed.
- Measurement of the general acoustic signal attenuation and the background noise as a base for the determination of the maximum distance between the sensors. Usually, this is done measuring the AE signals of a breaking pencil lead of defined thickness and hardness. This simulates rupture type signals in the test object. In case of paint or coating covering the surface, its acoustic damping behavior has to be tested in order to decide, whether the coating needs to be removed or the distances between the sensors are to be decreased, respectively. The determination of the maximum sensor distance is described in EN WI138076 and takes into account both the background noise as well as the material properties (amplitudes of the expected bursts at the source location).
- Installing the sensors according to a position plan, which takes the previously determined maximum distances as well as the complexity of the test object geometry into consideration.
- Check of the sensor sensitivity and the coupling quality, respectively, using pencil lead breaks and the automatic sensor-coupling test. This also includes a check and measurement of the sound velocity and damping between each sensor couple.
- Check of the location capabilities and influences of AE sources by complex parts of the structure, e.g. close to nozzles etc.

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- Establishing a safe communication line between the control units of the pressurizing and the AE testing systems, making sure, that in case of critical results being displayed, the pressurizing can be stopped immediately, or in case of danger the pressure can be decreased.
- Carrying out the pressure test with previously determined constant increase of pressure and well defined pressure-hold including data acquisition and on-line-monitoring.
- Having completed the pressure test, a second sensor-coupling test follows to make sure, the coupling quality has not changed during the test.
- Evaluation of the test results including a characterization of the sources.
- If required, the location results may be verified by test locations using pencil lead breaks.
- Crosscheck of the located AE sources using conventional NDT techniques.

7 AE Testing Standards

A number of European Standards prove that the AE testing method is widely accepted today:

EN473-2000:	Certification of Testing Personnel (including AE)
EN1330-9:	Terminology - Part 9: AE
EN13554:	AE Testing – General Principles
EN13477-1,-2:	AE Testing – Equipment Characterization
prEN (WI138076):	AE Testing of Metallic Pressure Systems During the Acceptance Test
prEN13445:	Non-Fired Pressure Equipment – Part 5: Inspection and Test, Appendix E: AE Testing

8 Conclusion

This paper can only give an overview of the AE testing method without entering into particulars. Its main purpose is to present the progress of the equipment technology made during the last years.

The high level of modern computer technology, measurement techniques, and software has generated an enormous increase of the range of applications, the reliability, and the significance of the AE testing method. Especially, the real-time location calculation provides a big advantage, as in many cases it allows to locate and to eliminate sources of interference or to distinguish their signals from those generated by defects.

Mechanical load is applied to make weak spots and defects start emitting acoustic signals. A considerably low number of sensors in fixed positions are sufficient to cover 100% of a large test volume. And it is sufficient if the test object is accessible at the sensor positions. Distances between sensors at metallic test objects are usually within a range of 3 – 6 m, depending on the local conditions. Distances between sensors on other material (plastic) may be considerably smaller (e.g. down to 20 – 50 cm).

The AE testing detects defects, which are growing under load during the test but does not recognize defects that are not moving.

Because of its capability to detect defects right at the moment of their growth, the AE testing method may also be used as a real-time monitoring and warning system to avoid a failure of the structure under test with possibly disastrous consequences. This capability also allows to use the storage medium, e.g. liquid gas or natural gas, for pressurization. So, the removal of the storage medium as well as the filling with water as medium for pressurization are no longer required. This drastically reduces the costs as well as harmful impacts on both, equipment and environment.

The AE testing method cannot be applied in each and every case. Anyhow, under good conditions it provides numerous considerable advantages, so why not take it into consideration much more frequently?

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