# TECHNICAL REVIEW

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# Contents

# Acoustic Emission

by

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## ABSTRACT

In the last decade Acoustic Emission (AE) has gained increasing recognition as an active method in the field of non destructive testing. This article describes the principle behind the technique as well as its advantages and limitations. As frequencies dealt with in Acoustic Emission are well above the audio range, special transducers, amplifiers and analysers have been developed to process the signals. The design principles and the construction of these instruments are briefly discussed and their use are illustrated by several practical examples.

## SOMMAIRE

Durant ces dix dernières années l'émission acoustique a pris une importance croissante dans le domaine des essais non destructifs. Cet article décrit à la fois le principe sur lequel repose cette technique et ses avantages et limites. Les fréquences concernées dans l'émission acoustique sont bien supérieures à la gamme audible, aussi des transducteurs et des analyseurs ont été conçus pour traiter ces signaux. Les principes de construction de ces appareils sont brièvement discutés et leurs applications illustrées par plusieurs exemples pratiques.

## ZUSAMMENFASSUNG

Die Schallemisionsanalyse (SEA) hat im letzten Jahrzehnt immer mehr Interesse gefunden als eine aktive Methode auf dem Gebiet der zerstörungsfreien Werkstoffprüfung. In diesem Artikel wird das Prinzip beschrieben und die Vorteile und Grenzen der SEA. Da die Frequenzen, die auf dem Gebiet der SEA interessieren, weit im Ultraschallbereich liegen, wurden spezielle Aufnehmer, Verstärker und Analysatoren entwickelt, um die SE-Signale zu verarbeiten. Die Konstruktion dieser Geräte wird angesprochen und an Hand verschiedener praktischer Beispiele illustriert.

## Introduction

In the field of Non Destructive Testing (NDT) a variety of methods exist today, e.g. microscopic and X-ray inspection, strain measurements and flaw detection by dye penetrants, eddy currents and ultrasonic transmission or reflection.

What these methods have in common are that they are all passive and are able to detect a flaw or a crack in the suspected region when the inspection is being carried out.

Acoustic Emission is a relatively new NDT technique and differs from the above-mentioned techniques in that it is an active method able to detect **when** a flaw or a crack occurs and sometimes **where** it occurs. However, the determination of **what** kind of a flaw, is normally left to the other methods.

## Literature Survey

It has been well known for centuries that wood and rock emitted noises when they started cracking or breaking. Later, similar noise was identified during the bending of tin bars which is often known as "tin cry".

This phenomenon was scientifically investigated in 1948 by Schockley et al. [1], however, the first pioneering work on acoustic emission (AE) was made in 1950 by Joseph Kaiser [2] at the Technical University of Munich. Here the noise emitted by the deformation of materials was examined by means of electronic equipment capable of detecting non-audible signals. One of the observations made, was that irreversible processes were involved with this phenomenon, an effect later named the Kaiser-effect.

In the next decade very little was published on AE, but in 1958 interest in this field was again shown by different scientists in the USA. During the next five years some 15 papers were published and in 1964 the first useful applications were reported. The same year, results from tests using equipment detecting only signals at frequencies considerably higher than the audio-range were published. This excluded most of the background noise (at the cost of higher structural attenuation) and was a major breakthrough for the application of AE.

A number of reports on AE applications appeared up to the end of the sixties when the amount of literature became voluminous and the first commercial equipment was produced. From then on, increasing interest has been shown and today the total number of publications is approaching around a thousand.

## Definition

AE (sometimes called Stress Wave Emission SWE) can be defined as:

> The elastic wave generated by the release of energy internally stored in a structure.

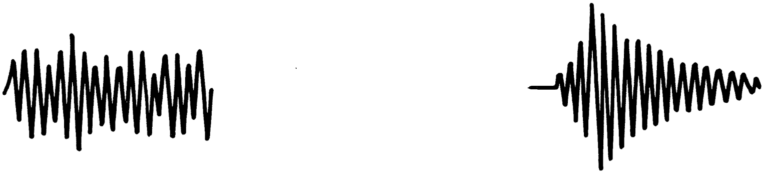
Although this definition includes many kinds of waves, (e.g. earthquakes and microseismic phenomena) AE-systems are designed to handle only a small part of the full spectrum. (Here mechanical shocks and clicks are not included, although AE-systems are used in some cases e.g. to detect loose parts).

## AE Sources

AE "Sources" which can be described as different processes emitting elastic waves, can be basically classified in 4 different groups:

1. Dislocation movements
2. Phase transformations
3. Friction-mechanisms
4. Crack formation and extension.

The signals emitted may be broadly divided into two types i) continuous emission (resembling white noise) and ii) burst-type emission, mostly detected as single decaying sinusoids due to resonances in the structure and the transducer. The two types of signals are shown in Fig. 1.



Continuous emission

Burst-Type emission

*Fig. 1. Continuous and Burst Type signals*

However, a clear distinction between the two types cannot be made, as there is no logical transition point.

For comparison purposes the amplitudes of the emitted signals from the different mechanisms are shown below:

| | |
|---|---|
| Dislocation movements | 1 - 10 |
| Phase transformations | 5 - 1000 |
| Crack formation | 20 - 1000 |

The amplitudes of the signals are affected by several parameters, some of which are shown in table 1.

| **Parameters yielding high amplitudes** | **Parameters yielding low amplitudes** |
|---|---|
| High strength | Low strength |
| High strain rate | Low strain rate |
| Large grain size | Small grain size |
| Low temperature | High temperature |
| Anisotropy | Isotropy |
| Inhomogeneity | Homogeneity |
| Cast | Wrought |
| Cleavage fracture | Shear deformation |

*Table 1.*

The energy released by a single dislocation movement (displacement of a particular type of line imperfection through the crystal lattice) is normally too small to be detected by AE equipment. However, many dislocations often combine to form an avalanche of movements giving rise to a continuous AE-signal.

The most well-known phase transformation is the martensite formation in carbon streel (face centered cubic to body centered tetragonal). The crystal lattice transformation propagates at about 1/3 the velocity of sound resulting in sudden energy release which is detected as a single burst signal for every grain transformed.

Crack formation occurs at surface notches or at points inside a material where local stresses exceed the fracture stress. The crack formation results in creation of new surfaces and strain energy is released which is partly transformed to AE signals. In some cases it has been possible to relate the energy in the measured signal to the energy calculated from fracture mechanics theories and the crack area.

The AE signals generated by the crack formation are of the burst type which are often emitted at a very high rate.

Friction occurs in cracks and between adjacent materials, and the sudden sliding mechanism releases burst type signals. These signals are useful for detecting and localizing cracks, but are troublesome when fracture theories are studied. However, these signals can often be eliminated by a drop of oil at the crack tip.

**Propagation**

The AE-sources behave in a manner similar to a radio antenna with a specific radiation pattern for the different wave types (shear-waves and compression-waves), but the position and properties are only known in special rare cases.

If the source emits a spherical wave packet, it will be propagated as such, only in an infinite isotropic, homogeneous, ideally elastic medium.

Fig.2 shows a sketch of the radiation pattern in a plane perpendicular to the slip-plane and containing the slip-direction vector.

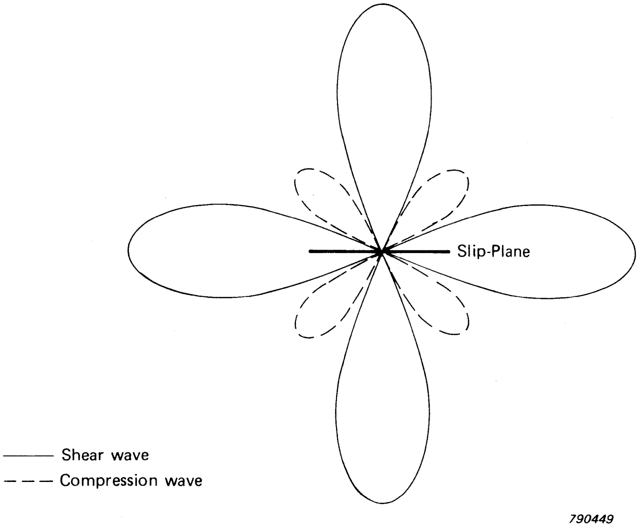


*Fig.2. Radiation pattern from a source*

In real structures the propagation will be affected by:

Surfaces (which create reflections and formation of surface waves (Rayleigh or Lamb)).

Grain boundaries, microcracks, inclusions etc. (which create reflection and diffraction).

Anisotropy (which causes deformation of the spherical wave packet (e.g. to an elliptic one) on account of the difference in wave velocity in different directions).

Inhomogeneities (which distort wavefronts).

Non-linear elastic behaviour (which is responsible for damping and dispersion (frequency dependence of the velocity)).

An important example is waves propagating in a plate, especially on large structures like pressure vessels where source location techniques are used. These waves are subject to dispersion as shown in Fig.3. $a_n$ and $s_n$ denote the antisymmetric and symmetric waves of the n'th order.

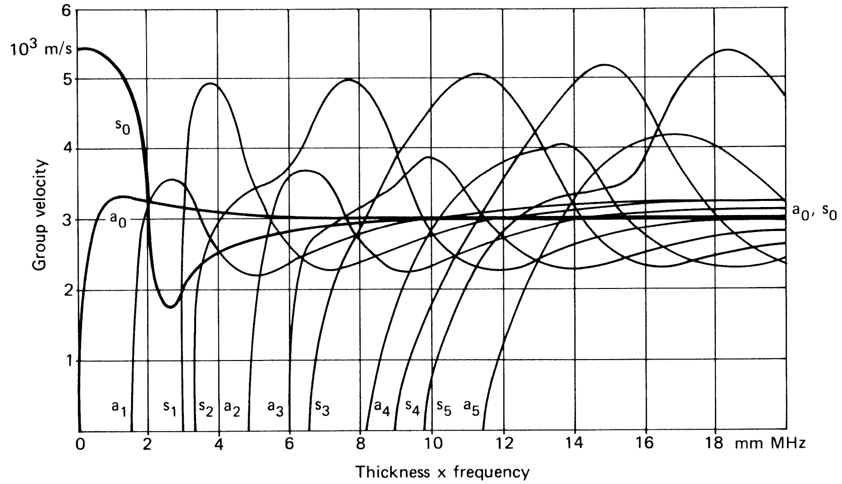


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*Fig.3. Surface wave modes in a Steel plate*

It can be seen that the dispersion relationships are complicated, making it difficult to predict the exact group velocity involved. Furthermore, dispersion changes the waveform which introduces ambiguities when time differences have to be measured for localization.

The above factors make it extremely difficult to study the source mechanisms except under conditions especially designed for the purpose.

However, research is still being carried out in this field,which will further enhance the usefulness of the AE technique.

It should be noted, that in most of the present applications it is not necessary to have a detailed knowledge of the source mechanisms and the propagation. These applications include, for example the quantitative determination of the destruction of test pieces and localization on large steel structures where a certain amount of ambiguity can be tolerated.

## AE Transducer Principles and Calibration

When the emitted stress wave reaches the transducer position via a propagation path as shown in Fig.4 the stress-strain condition has to be converted into an electrical signal which can be treated by electronic means.

Different principles can be used to perform the transduction. Optical heterodyne techniques can be used as well as simple capacitive electrodes placed a few $\mu$m from a polished surface.

A more practical capacitive transducer is a PETP(polyethylene terephthalate)film with a thickness of 25$\mu$m and a metallic coating on one side. This type of transducer has been used to study the details of AE-waveforms as it is linear up to several MHz, but its sensitivity is about 100 times lower than that of the undamped piezoelectric types at resonance.

The piezoelectric (PZ) transducers are by far the most widely used. They are mostly undamped having very high sensitivities at resonance. The piezoelectric material can be quartz or lithiumniobate crystals but is normally a ceramic of the lead titanate zirconate family. These ceramics are produced by sintering of the ferroelectric material followed by polarization at a high voltage between proper electrodes.

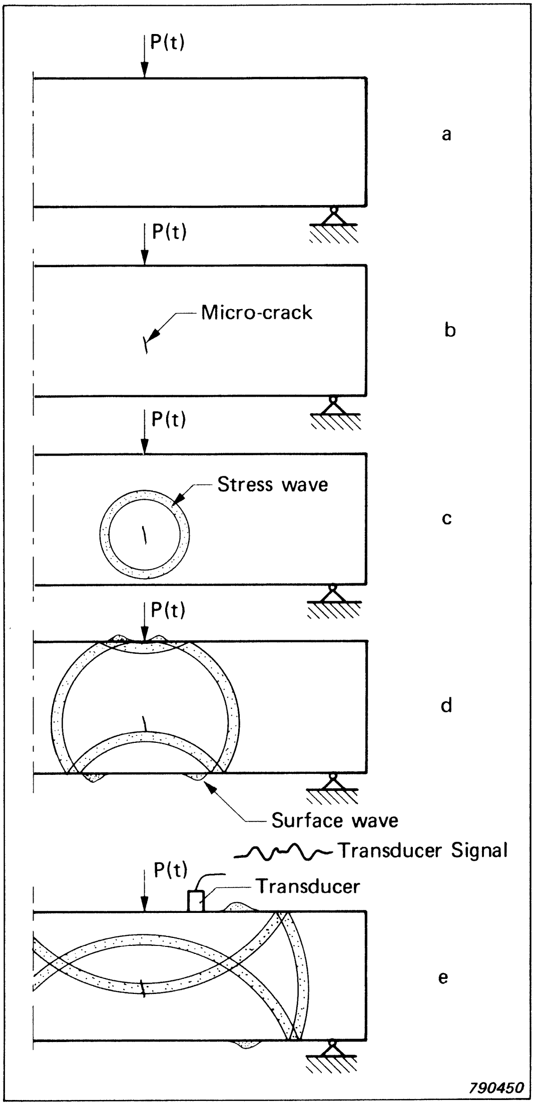


*Fig.4. Propagation of a stress wave in a specimen*

Fig.5 shows two main configurations together with the amplitude response at low frequencies. In this context low frequencies are well below any transducer resonance.

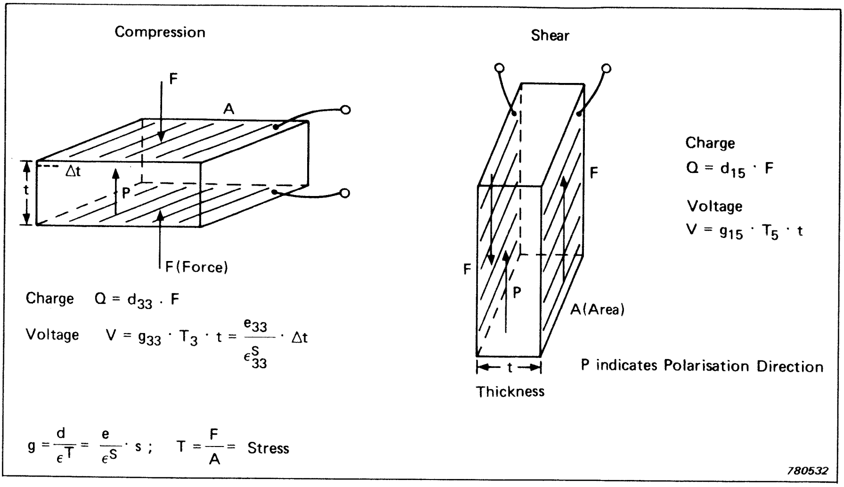


*Fig. 5. Response of Piezoelectric crystal to slow excitations in the compression and shear configurations*

A simple disc with electrodes mounted on its faces, perpendicular to the polarization direction is often used for AE and ultrasonic transducers.

For a plane infinite disc adjoining a structure and a damping material, the response to an incoming plane wave with normal incidence can be calculated.

It has to be stressed that this is a typical situation for ultrasonic applications, but **not** for AE signals which are in most cases mainly surface waves, (Rayleigh or Lamb). The volume waves are attenuated by $1/D$ where D is the distance from the source while surface wave amplitudes are reduced only by $1/\sqrt{D}$.

Ultrasonic transducers and their calibrations are not suitable for AE purposes. This is illustrated in Fig. 6. A PZ-disc 1,9 mm thick and 9 mm in diameter is mounted directly on a steel structure. The thickness mode can be calculated to be 1 MHz, but a surface wave of 1 MHz ($\lambda$ = 3 mm) will not give any output as seen from the symmetric deformation on the figure, whereas a wave corresponding to $\lambda/2$ = 9 mm, (f = 167 kHz) will couple strongly.

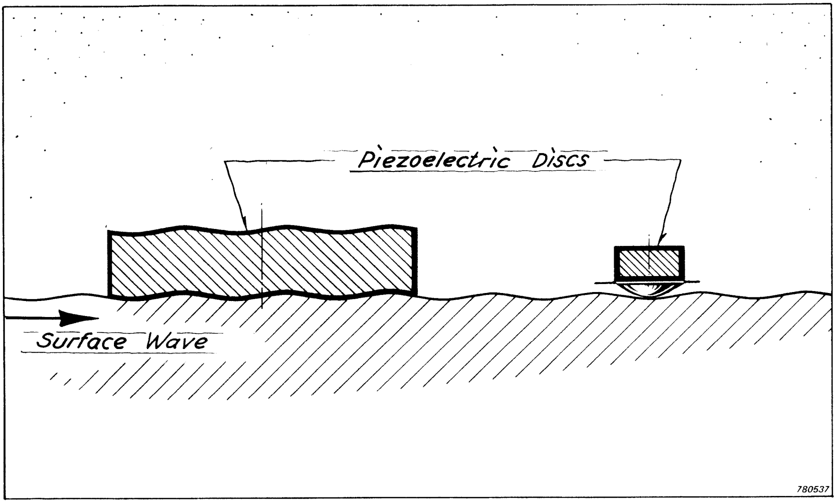


*Fig. 6. Coupling of surface waves to two different transducers*

To overcome this problem the disc can be made small, however, the capacitance of the disc reduces considerably resulting in a much lower sensitivity when loaded with external capacitances from cable etc. If a large plate is used for coupling to the structure, it is difficult to ensure coupling at the point opposite the piezoelectric disc. If a small plate is used tilting may become a problem.

The transducer construction shown in Fig.7 with details shown in Fig.6 overcomes these problems. The integral preamplifier ensures a small capacitive loading. The membrane suspension gives an appropriate coupling force and the slightly spherical plate ensures adequate coupling.

Some precautions should be taken in the mounting of transducers to ensure good results. The surface on which the transducer has to be mounted must be flat and clean to permit effective coupling. Scale and rust must be removed e.g. by grinding. Even though the surfaces may be flat and clean only a few points are in direct contact.

By using a drop of oil, grease or high viscous "goop" (e.g. Dow Chemicals 276-V9), the voids are filled and the stress waves can be transmitted to the transducer. If a permanent installation is desired, various adhesives may be used. Transducers coupled with fluids must be kept in place by elastic bands, adhesive tape, springs or fixtures as is practical.

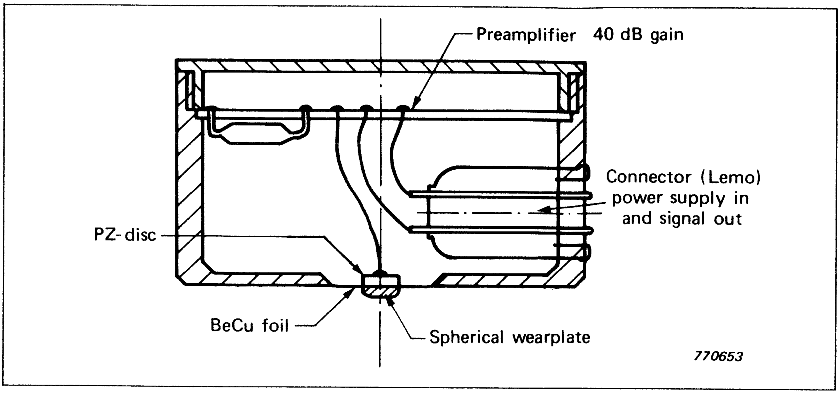


*Fig. 7. Details of transducer construction*

The transmission of plane waves through the coupling layer can be calculated in the same manner as the frequency response. In general, it is desirable to make the coupling layer as thin as possible to get maximum sensitivity.

Several methods have been proposed for calibration. Many of these are inspired by the AE phenomenon itself and use transient pulses generated by breaking of pencil leads, glass capillaries or by spark impact. Others use continuous sources like gas jets (broad band random signal) or transducers used as transmitters.

If these "sources" have a sufficiently broad frequency spectrum and if the transmitting structure permits transmission of the whole spectrum without distortion, they may be used for sensitivity comparison and relative frequency response determination of AE transducers. If an absolute calibration is desired a detailed knowledge about the source and structure is necessary.

At the National Bureau of Standards, Washington D.C. basic research is undertaken to find suitable methods but no method has yet been generally accepted.

Most commercial transducers available today are calibrated in the same way as ultrasonic transducers in a face to face configuration where no surface waves are generated at all.

These calibrations are of limited value if the transfer function from sur-

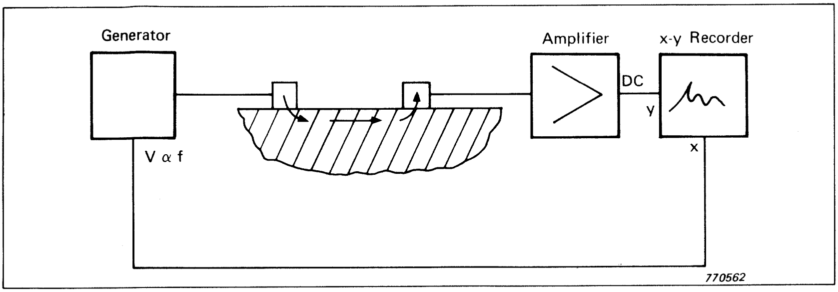


*Fig.8. Set-up for Reciprocity Calibration*

face waves to electrical signals is required.

A different method proposed by Hatano [3] is used at Brüel & Kjær. This method is based on the reciprocity principle which is well known in network theory, and also used for calibration of microphones, hydrophones and vibration transducers.

Fig.8 shows the set-up used for the reciprocity calibration. A warbled tone signal is applied to a transmitting transducer which excites Rayleigh waves in the medium. These surface waves are detected by the receiving transducer normally positioned 200 mm from the transmitter.

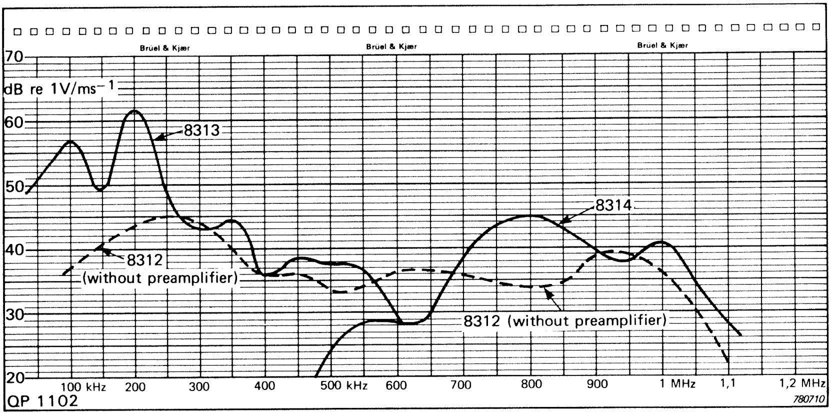


*Fig.9. Typical frequency response curves for the acoustic emission transducers*

The output signal is amplified and a DC voltage proportional to the RMS value of the signal is supplied to the Y input of an X-Y recorder. A voltage proportional to the centre-frequency of the warbled tone signal is fed to the X-input of the X-Y recorder. The current to the transmitting transducer is measured using the same set-up.

Absolute calibration is achieved by performing three consecutive measurements as described, by mutually interchanging the transducers.Typical calibration results for the Brüel & Kjær AE transducers types 8312, 8313 and 8314 are shown in Fig.9.

### Amplification

The transducer is followed by a preamplifier - amplifier combination giving up to 100 dB total amplification.

The preamplifier is often the weak link in the measuring chain governing the lowest measurable signal determined by its noise level.

For meaningful comparison of preamplifiers, the noise should be measured and compared when the input is loaded by the transducer impedance. If suitable modern electronic components are used, the noise level will be determined by the thermal noise of the piezoelectric disc as in the B & K Preamplifier Type 2637. The minimum detectable amplitude for a transducer in the 200 kHz range is of the order of $10^{-14}$ m at room temperature.

If filtering is desired it is preferable to have it as close as possible to the beginning of the measuring chain.

The preamplifier is often connected to the amplifier with a 50 ohm transmission line to permit long cables and to minimise influence from electromagnetic noise signals.

The amplification is normally variable in steps of a few dBs and the bandwidth of the amplifiers is often between 50 kHz to 2 MHz (approximately).

### Detection and Registration

The information carried by the primary unfiltered and amplified signal is only preserved if the storing medium has the appropriate frequency and dynamic range and the size required to collect data during the testing period. This is rarely possible, and in many cases not desirable.

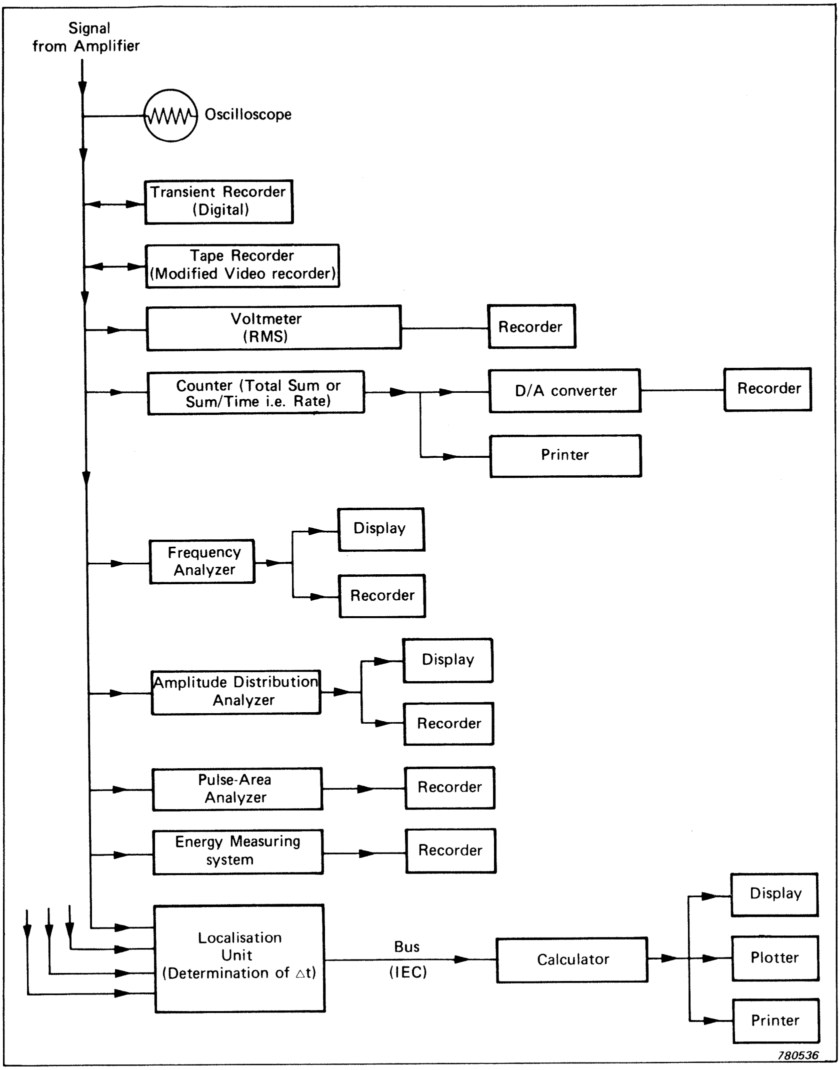


*Fig.10. Block diagram for various analysis and calibration systems for acoustic emission*

Consequently, different kinds of data reduction systems are used. Fig.10 shows some of the possibilities.

The oscilloscope is always very useful to get an immediate impression of the activity.

The tape recorder which is normally a modified videorecorder or special instrumentation recorder is useful when analysis has to be carried out later, or when analysis of multiple channels is desired. However, the dynamic range is often very limited (~ 30 dB).

The transient recorder is useful when single pulses have to be analysed. The stored signal can be played back at different rates either on an oscilloscope, or a level recorder or it can be frequency analysed. Dynamic range and memory size are limited (e.g. 8 bits resolution ~ 48 dB and 1 - 2 K words).

The RMS voltmeter with a recorder and the frequency analyzer are well known measuring instruments. The analysis of the distribution of peak amplitudes are also known from other measuring fields.

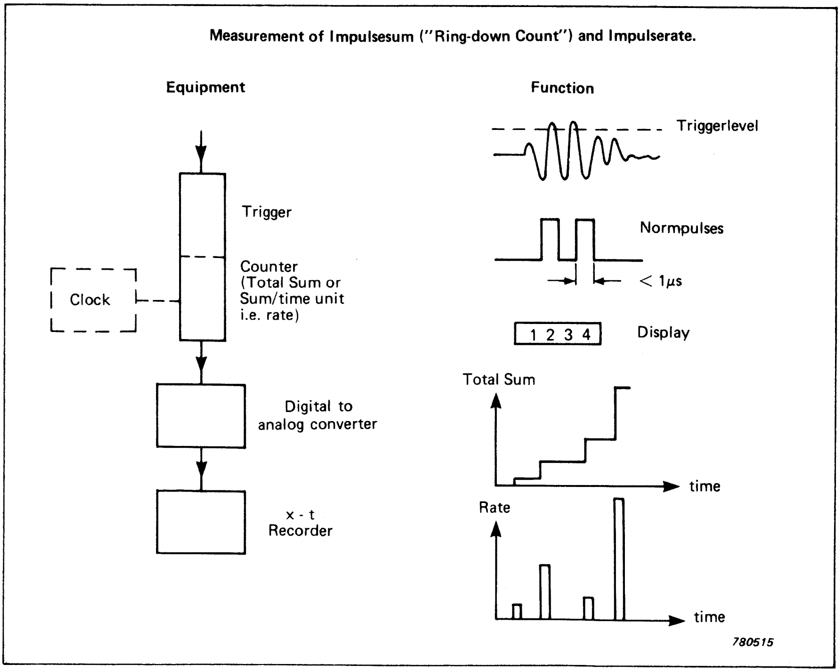


*Fig. 11. Measurement of "Ring-down Count" and Impulse Rate*

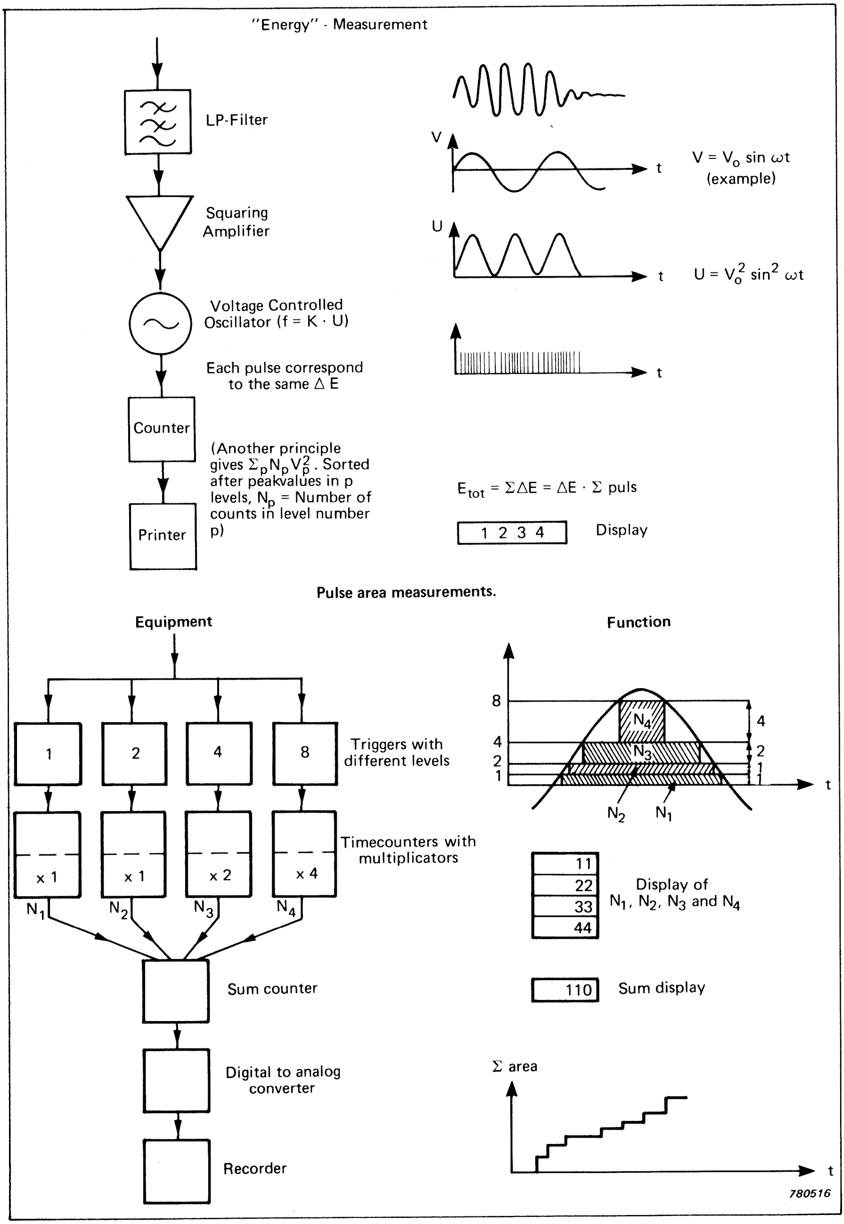


*Fig.12. Energy measurement and Pulse Area measurement principles*

The use of counters shown in Fig. 11 is most widely used in AE-measurements, although other methods have obtained recognition during the last few years.

If the counter is blocked for some milliseconds after each triggering, a single decaying sinusoid will only give one count, called an "event".

Two other measuring methods are shown in Fig. 12 (see News from the Factory under Pulse Analyzer).

If the position of a source is of interest, systems with two or more channels can be used as shown in Fig. 13. The time difference measured between a pair of transducer signals determines a hyperbola in a plane if the propagation velocity is known. The intersection of hyberbolas obtained from other transducer pairs defines the location of the source.

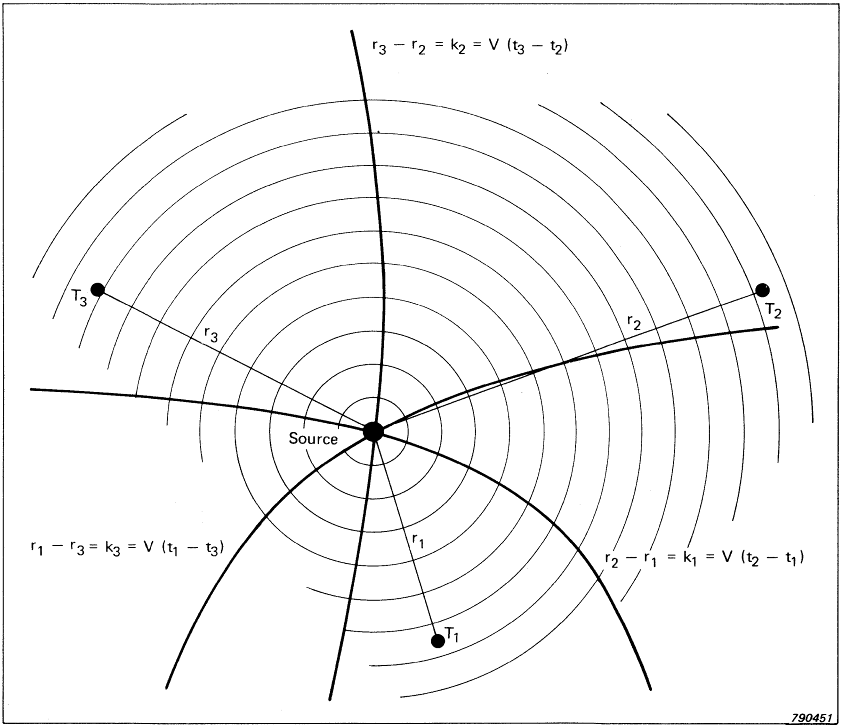


*Fig. 13. System for localisation of sources*

## Choice of parameters

Although rules for the application of the different measuring principles cannot be generalised a few points can be mentioned.

First, a distinction between the continuous and the burst type of signals can be made.

For continuous emission the RMS value is most suitable and physically also most meaningful.

For the burst type signals an indication of total damage or rate of damage occurring is indicated by ring down counting, energy counting or pulse area measurements.

"Energy" counting places more significance on high amplitude signals, but is often limited in frequency and dynamic range.

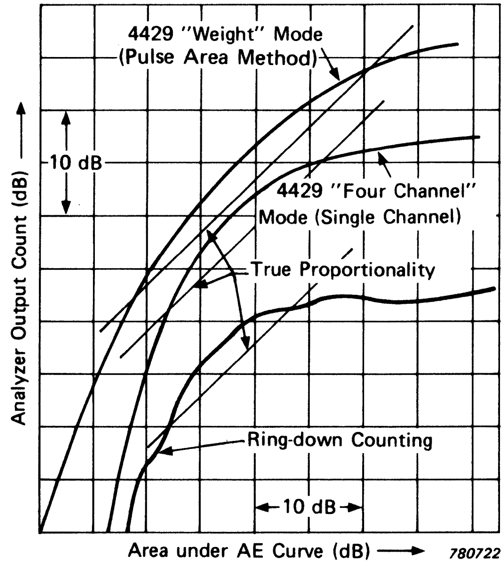


*Fig. 14. Relationship between area under the AE curve and output count for various methods of quantising AE activity. The curves are separated for clarity*

Pulse area measurements can be applicable to high frequencies and give an approximately linear relationship between the signal amplitudes and the output over approximately 30 dB when 4 levels are used. A linearity comparison with ring down counting is shown in Fig.14. Furthermore, a signal, which near the source is a short burst giving a certain ring down or energy counting, will be reduced in amplitude and spread out in time after a certain path length, giving large changes in ring down and energy but smaller changes in pulse area.

In some cases a fast peak detector with a decay time constant suitable for level recorders will give a good indication of activity and the output can also be used for amplitude distribution analysis.

If a more detailed knowledge of the nature of the source is of interest, some of the more sophisticated methods must be used.

A detailed analysis of the waveform may reveal details about the source event.

The frequency spectrum and the amplitude distribution depend on the nature of the source, the transmitting medium and the detecting system and is mostly used to detect changes in the source mechanisms, when the source location is fixed.

The amplitude is related to the energy of the source, but depends critically on the propagation path.

Multichannel systems are used for source location e.g. on large pressure vessels, but can also be used to discriminate between signals coming from a certain area of interest and signals arriving from other areas.

### Fields of application

The study of plastic deformation and crack formation and extension are two of the frequently reported application areas.

Fig.15 shows sketches of two typical results from plastic deformation of test pieces.

For Lüders deformation the decrease in stress is due to the formation of slip-bands (Lüdersbands) which travel with irregular velocity through the test piece. This continues until the end of the Lüdersrange when work-hardening starts and the AE activity decreases. It can be seen

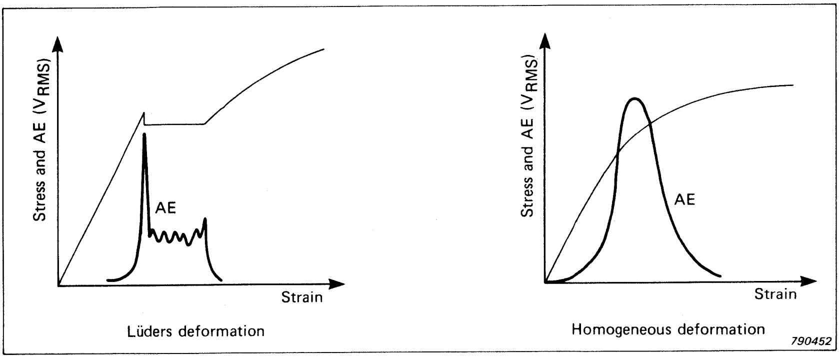


*Fig. 15. Stress and Acoustic Emission activity as a function of strain for two types of plastic deformation*

that a sudden decrease in load implies high AE-activity corresponding to high slip-band velocity.

For homogeneous deformation the movement of dislocations occurs all over the test piece until they are finally trapped and the AE activity decreases.

On account of the AE-activity associated with crack formation it was one of the first areas of application for AE techniques. If the AE-activity increased significantly before failure it could be used as a direct warning.

Fig.16 shows results obtained from a fatigue test on a notched specimen, where the increase in AE activity before failure is quite noticeable.

Metallurgists and scientists working with fracture mechanics have adopted AE as a valuable tool, as correlation between AE amplitude and fracture toughness parameters can be used to determine critical values of the J-integral and the COD (Crack Opening Displacement).

Because AE signals are generated by most materials when deformed, and may be detected over the entire surface of a structure, AE analysis has a large number of applications limited only by the detection possibilities.

In industrial applications the AE technique can be used for testing and

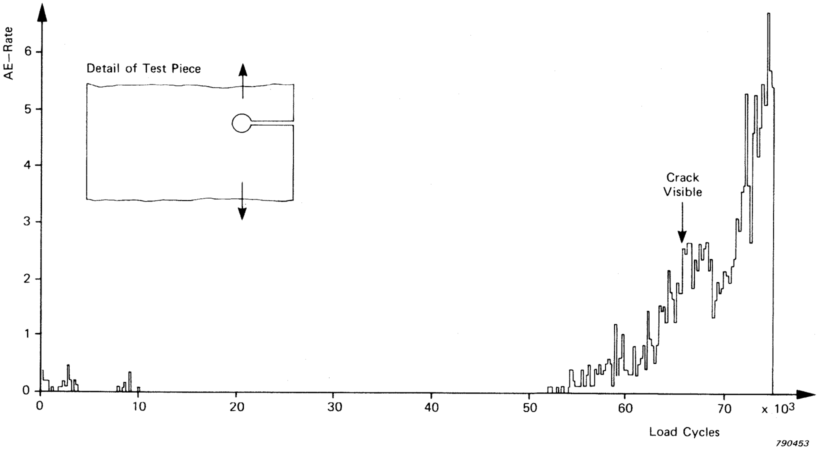


*Fig. 16. Impulse Rate as a function of load cycles for a fatigue test on a notched specimen*

monitoring of structures. The purpose of AE analysis in these application areas is to detect, locate and evaluate flaws, fractures and other faults. While the evaluation is still a difficult area where other NDT methods are normally used, the detection and localization capabilities are generally recognized.

Methods and instrumentation developed for AE can also be used for other applications. Faults in bearings, which often cause expensive

| Fabrication | | Later Inspection | |
|---|---|---|---|
| Duration fabrication | Final test | Proof testing | Continuous monitoring |
| Welding | Pressure testing of vessels and pipelines | Vessels and pipelines | Vessels and pipelines |
| Heat treatment | | Bridges | Buildings — bridges |
| Hardening | Construction | Rotating machinery | |
| Phase transformation | Bonding | | Mines |

*Table 2.*

breakdowns in industry, result in mechanical noise dependent on the type of fault and may be detected on the outside of the bearings and analysed as AE signals. Other examples of related applications are loose particle detection and leak testing.

A list of industrial applications is shown in Table 2.

**Advantages and limitations**
Some of the advantages and limitations mentioned are summarized and listed in Tables 3 and 4. On account of the low attenuations of AE signals in the 100 kHz range in metallic structures, flaws may be detected several meters from the transducer. For concrete and masonry structures low frequencies should be used or higher attenuation has to be accepted.

Remote detection and location of flaws.
Integral method (The entire structure is covered).
The measuring system can be set-up quickly.
High sensitivity.
Requires only limited accessibility to test objects.
Detects active flaws.
Only relatively low loads are required.

*Table 3. Advantages*

The structures has to be loaded.
AE activity is highly dependent on materials and the coupling method
Spurious sources can be difficult to detect.
Limited accuracy of localization.
Gives limited information on the type of flaw.

*Table 4. Limitations*

The main limitation of this method is that acoustic emission has to be generated by releasing the stored energy. This energy has to be supplied, normally in the form of application of load on the structure.

An important group of problems in AE measurements arise from the signals generated by electromagnetic noise sources (e.g. from switching, welding etc.) and by mechanical noise (e.g. from clamps or rotating machinery).

## Examples of Practical AE measurements

*Simple bending test of glass fibre reinforced plastic (GFRP) specimen*

A simple set up for a 3 point bending test is shown in Fig.17.

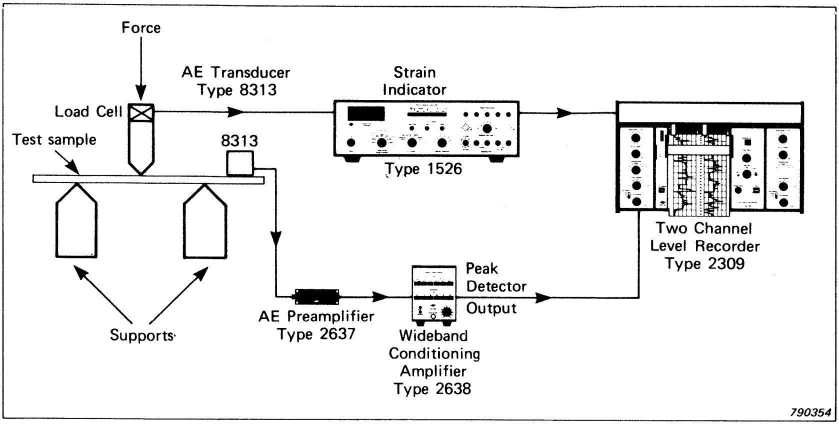


*Fig.17. Measurement set-up for a three point bending test*

The load on the specimen is measured by a set of strain gauges connected to the Strain Indicator Type 1526. The load and peak signals are recorded simultaneously by the Two Channel Level Recorder Type

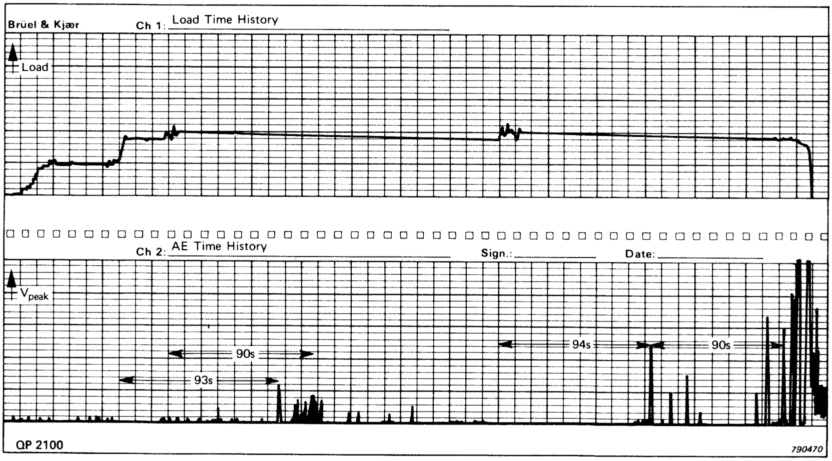


*Fig.18. Load and Peak signals are measured as a function of time on a Two Channel Level Recorder Type 2309*

2309. The AE-activity is measured by The Acoustic Emission Resonance Transducer Type 8313 connected to the AE Preamplifier Type 2637 and the Wideband Conditioning Amplifier Type 2638.

Fig.18 shows some results from a 2 × 20 × 160 mm glass fibre reinforced plastic (GFRP) specimen.

The load is applied in steps, and it can be seen that it decreases after each step due to the increased compliance of the specimen. An approx. 90 second relaxation time constant seems to be present. The increase in activity gives a clear warning before fracture.

If a Noise Level Analyzer Type 4426 is connected in parallel to The Level Recorder Type 2309 at the peak detector output of Type 2638, an amplitude distribution analysis can be made and recorded by the Level Recorder Type 2306, as shown in Fig.19.

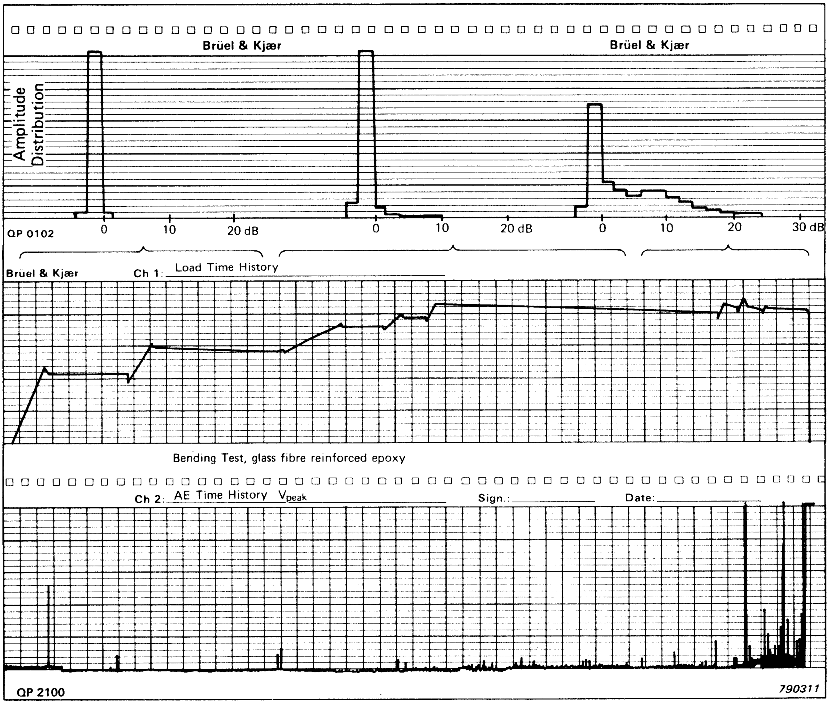


*Fig.19. Amplitude Distribution Analysis*

3 distributions are shown each covering the indicated part of the test time. The first indicates practically only the noise level. The second shows some amplitudes up to 10 dB over the noise peaks, probably due to debonding between the fibres and the matrix. The last distribution shows amplitudes up to 24 dBs over the noise peaks, due to fibre breaking. This distribution does not contain the fracture activity.

The decay time constant of the 2638 is set to 0,2 sec. to enable recording. If amplitude distributions are desired at a faster rate by the 4426, the time constant can be modified.

*Tensile test on carbon-fibre braid*
A tensile test on a 2 × 10 mm$^2$ specimen of carbon-fibre braid was performed with the set-up shown in Fig.20.

Three recording channels were used for load, peak output and "weighted sum" or accumulated pulse area which is given as an analog linear output from the AE Pulse Analyzer Type 4429. The transducer used is The Broad Band AE Transducer Type 8312.

Fig.21 shows the results. The load increases linearly and the activity gradually increases. It is seen that the weighted sum is easier to evaluate than the peak output.

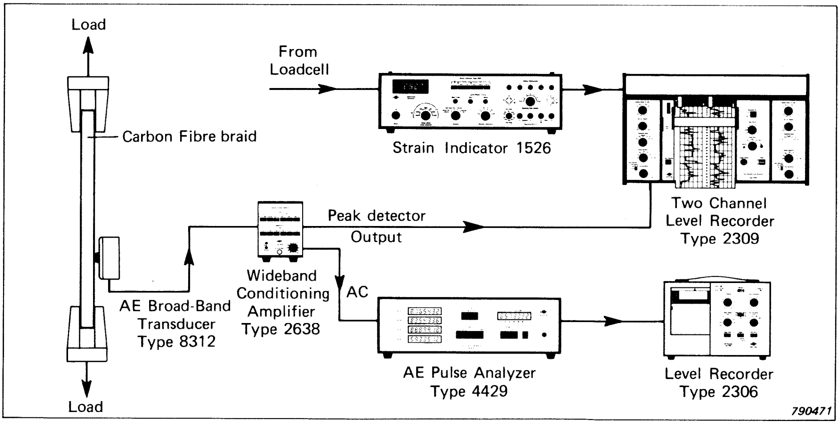
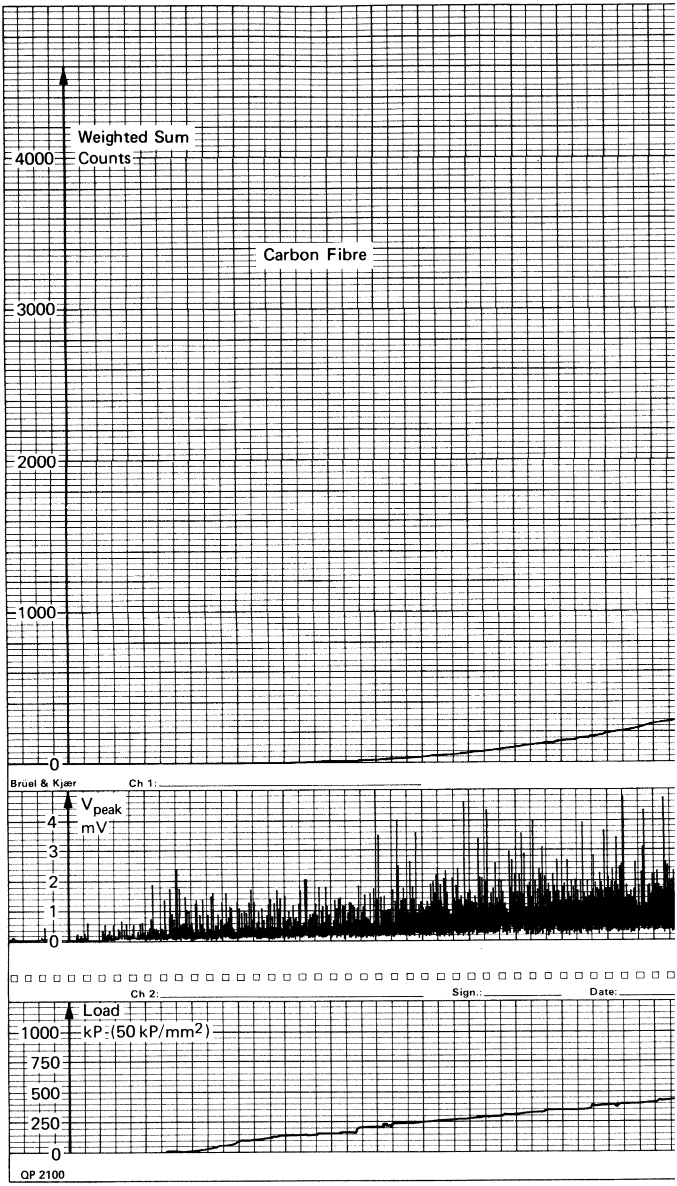


*Fig.20. Tensile test on carbon-fibre braid*


Weighted Sum
Counts
4000
3000
2000
1000
0
Carbon Fibre
Brüel & Kjær
Ch 1:
Vpeak
mV
4
3
2
1
0
Ch 2:
Sign.:
Date:
Load
kP (50 kP/mm2)
1000
750
500
250
0
QP 2100

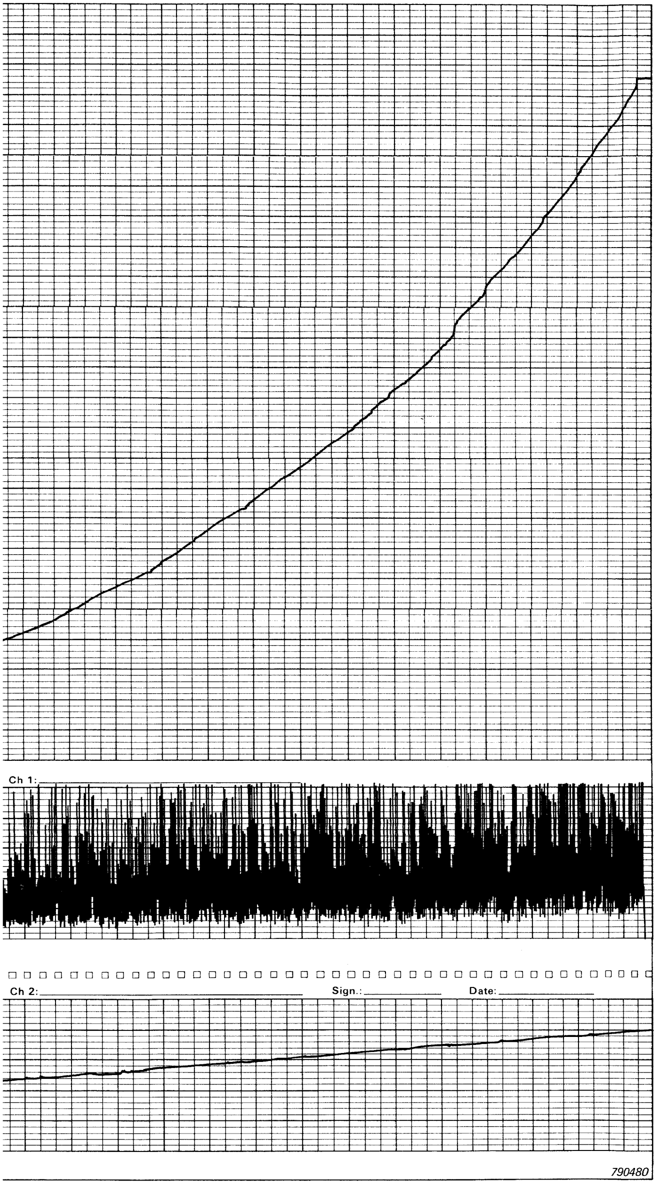


*Fig.21. Load, Peak Output and "Weighted sum" as a function of time*

*Test on a pressure vessel*

Using a set-up shown in Fig.17, but with a pressurized steel (H II) vessel as specimen and a pressure transducer instead of the strain gauges to monitor the water pressure in the vessel, the results shown in Fig.22 were obtained.

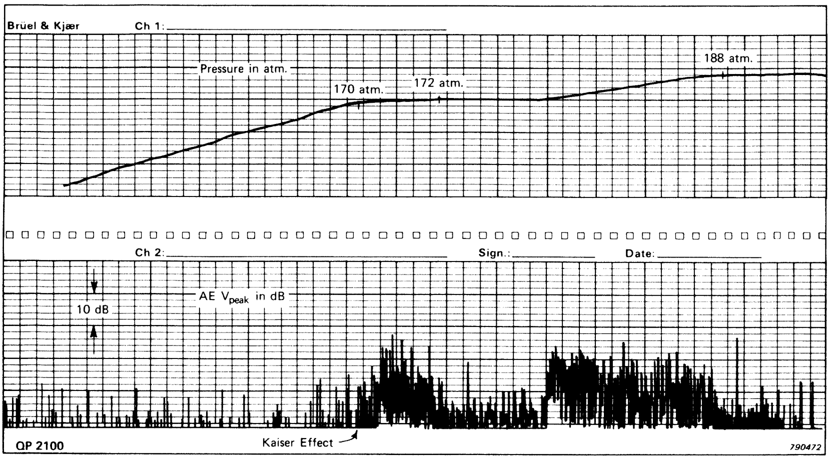


*Fig.22. Pressure and Acoustic Emission acitivity as a function of time illustrating the Kaiser effect*

The onset of the activity demonstrates clearly the Kaiser effect. As the maximum previous pressure was 170 atm the activity increases rapidly when that level is exceeded. The activity is recorded using a 50 dB logarithmic scale (the previous examples used linear scales). It is also obvious that the activity decreases when the pressure is kept constant.

*Localization on pressure vessel*

On the above-mentioned pressure vessel, a localization system shown in Fig.23 was used.

Different techniques were attempted using both direct on line calculations of source positions and storing results on magnetic tape for later analysis.

Fig.24 shows locations on the two ends of the vessel which are folded out. A part of the weld near transducer 5 shows increased activity.

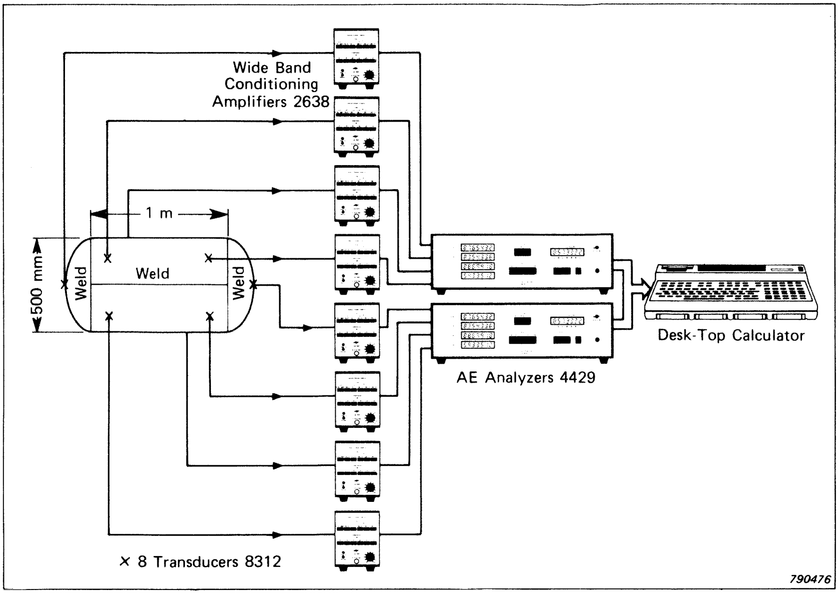


*Fig.23. Measurement Set-up for localization of sources*

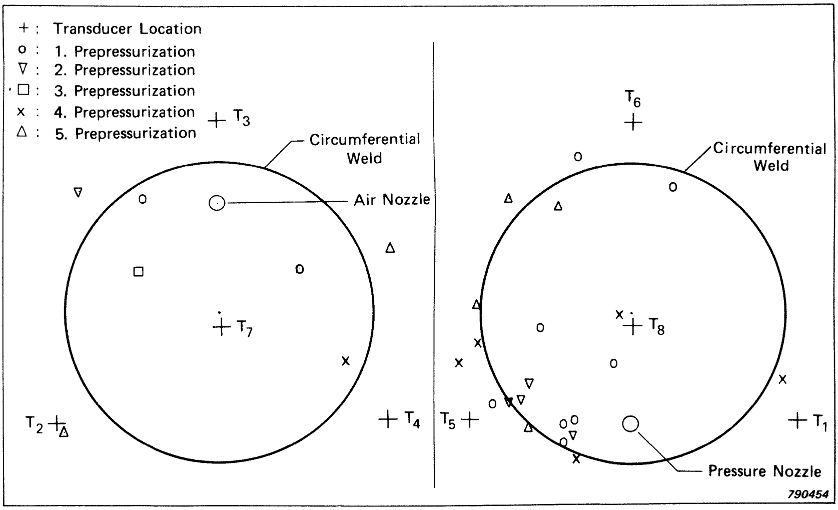


*Fig.24. Locations of the sources of emission on the two ends of the pressure vessel folded out*

*Two Channel localization*

When a test specimen such as shown in Fig.25 is loaded, acoustic emission is generated at the loading points due to deformation and friction and at the crack tip. To be able to distinguish between the two sources of acoustic emission, a theoretical analysis was first carried out, to determine the time difference between signals to arrive from any point on the structure to the two transducer positions marked X.

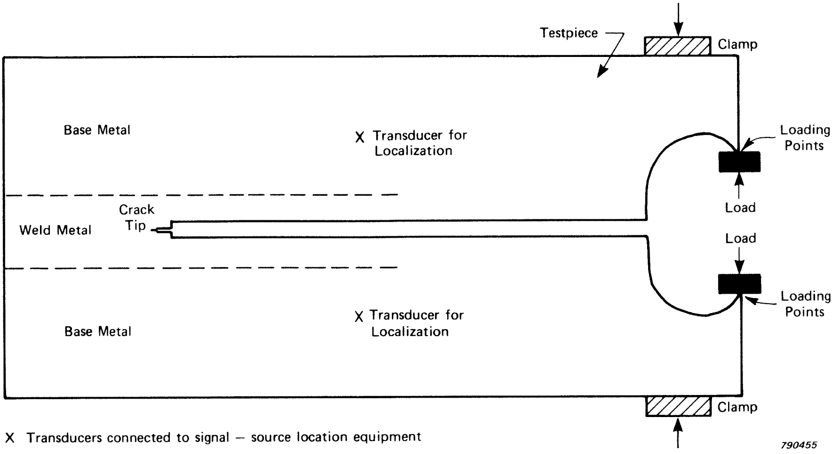


*Fig.25. Test specimen for differentiating two sources of emission*

Fig.26a shows theoretically calculated regions with different channel numbers corresponding to the various time differences. For practical measurements pencil leads were broken on the specimen to generate an artificial source and the time differences measured for the signals to arrive at the two transducer positions. The results are shown in Fig.26b and are found to be in good agreement with the theoretical values. A set-up shown in Fig.27 was used to store and display the time differences.

The test piece was now clamped and loaded above the expected fracture load. The acoustic emission was measured and found to be mostly in channel numbers ±13 as shown in Fig.28a indicating that the activity was generated at the loading points. To ensure that no deformation and friction occurs at the loading points when the clamp is removed the specimen was loaded once again above the expected fracture load with the clamp on. Fig.28b shows again the acoustic emission in channels ±13 and some in channel 0. The clamp was now removed and the test

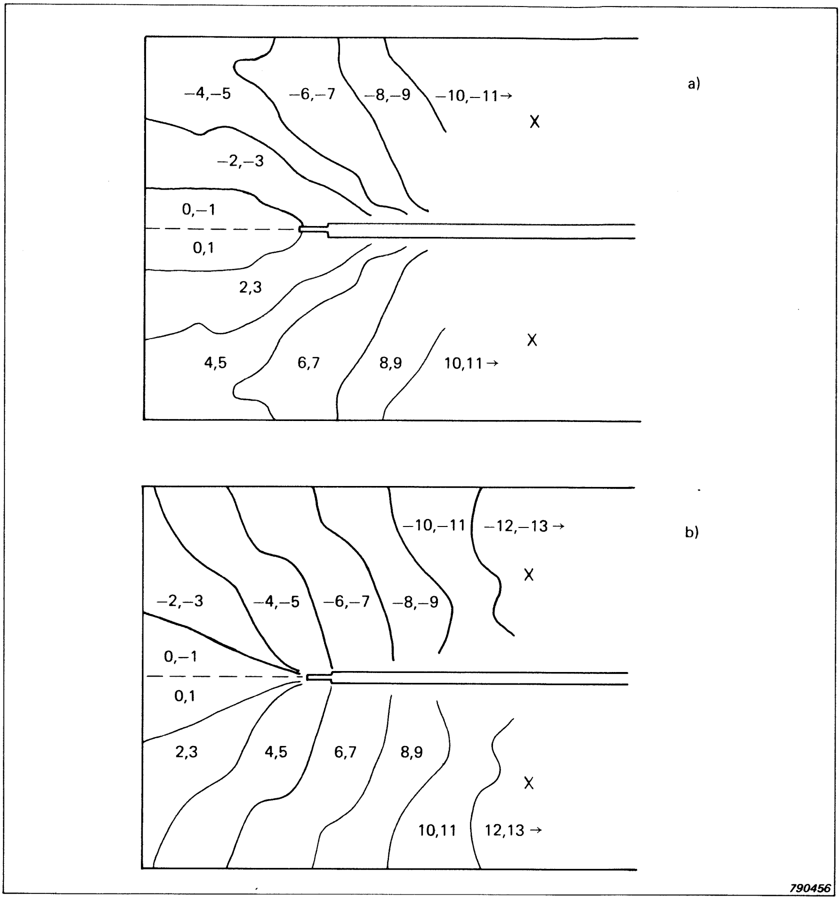


*Fig. 26. Time differences (channel numbers) for the signals to arrive from the regions shown to the two transducer positions*
*a) Theoretical*
*b) Measured*

performed by applying suitable load. The acoústic emission measured is shown in Fig. 28c and it can be seen that most of it lies in channel 0 indicating that the activity is generated at the crack tip.

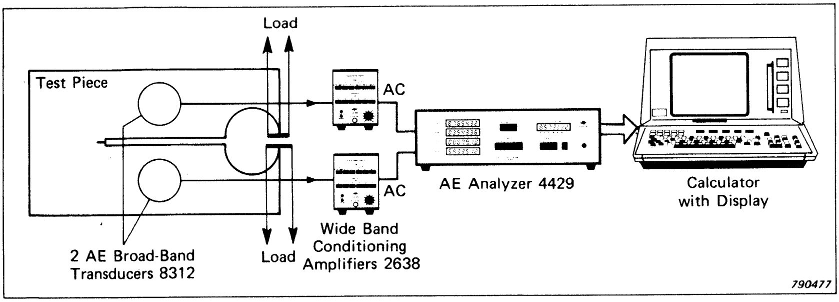


*Fig. 27. Set-up for storage and display of time differences*

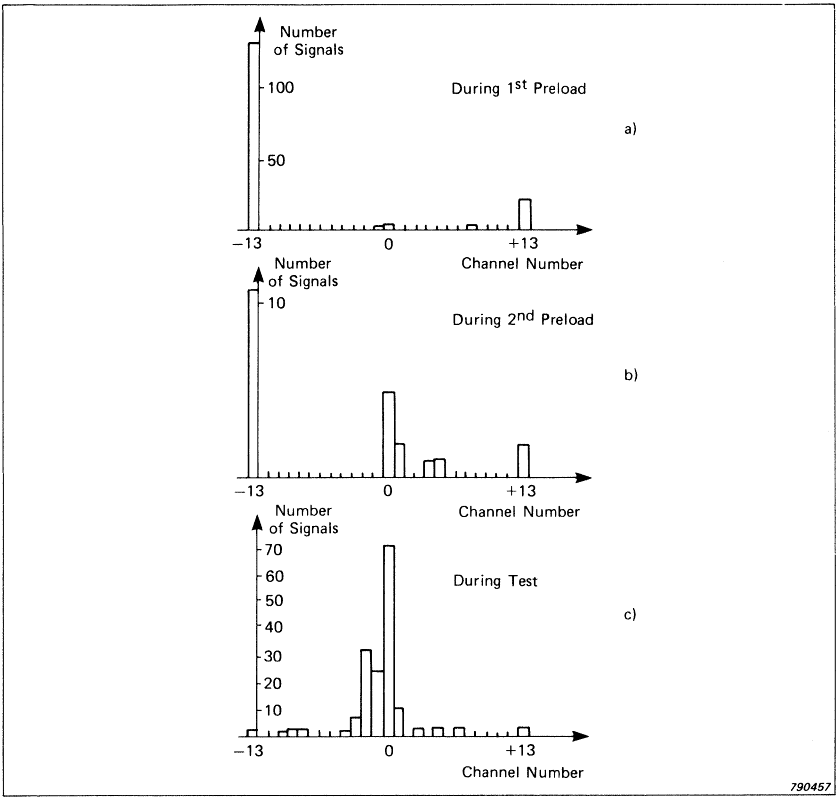


*Fig. 28. Amplitude distribution as a function of channel numbers (time differences) a) During first preload b) During second preload c) With clamp removed*

*Compression tests on concrete*

Some tests were carried out on concrete cylinders under compressional load using the set-up shown in Fig.29. Different parameters were recorded to find the most suitable one. Fig.30 shows activity measured as weighted sum rate (per 1 sec) with logarithmic output, and with linear output.

The weighted sum rate with linear output is probably the most suitable one to give an early warning.

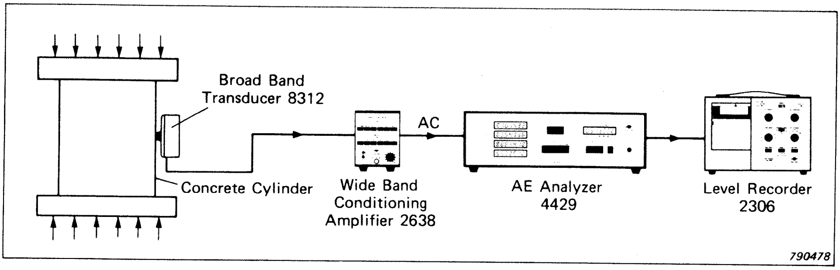


*Fig.29. Set-up for compression load test on concrete cylinders*

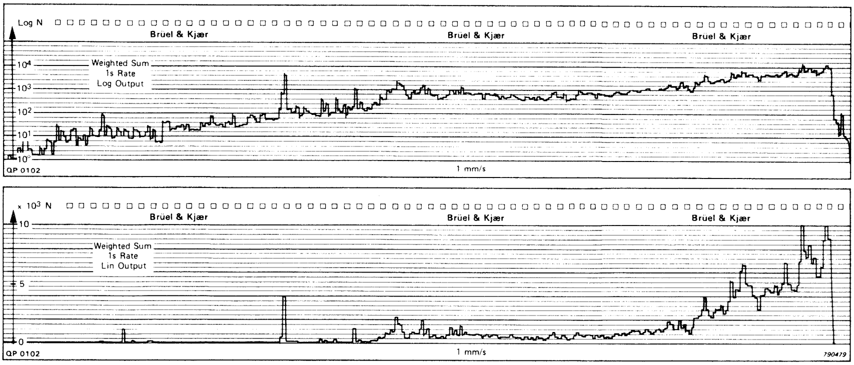


*Fig.30. Acoustic Emission Acitivity as a function of time*

## Acknowledgements

We wish to thank W.E. Swindlehurst from Risø National Laboratory and A.Nielsen and P. Krarup from the Danish Welding Institute for their cooperation in obtaining some of the results.

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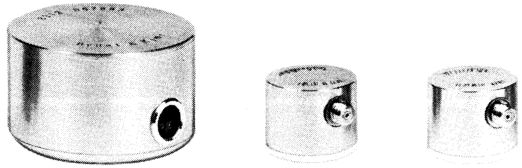
# News from the Factory

In the last decade Acoustic Emission (AE) has gained increasing recognition as an active method in the field of non destructive testing. To fulfil the growing requirements of this technique, Brüel & Kjær have developed a complete range of instrumentation, namely Transducers Types 8312, 8313 and 8314, Preamplifier Type 2637, Wideband Conditioning Amplifier Type 2638 and Pulse Analyzer Type 4429.

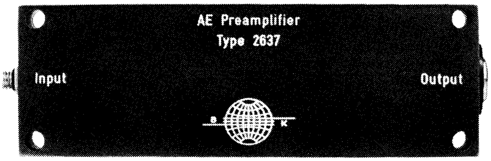
## Acoustic Emission Transducers Types 8312, 8313 and 8314



As no single transducer can fulfil the demands of a wide range of applications in AE technique, three different transducers have been developed. Type 8312 has a high sensitivity over a very wide frequency range making it suitable both for general AE detection work and for applications where the frequency content of AE signals has to be examined. The frequency response is flat (approximately ±10 dB) over the frequency range 100 kHz to 1 MHz. The built-in preamplifier with low impedance output allows it to be used with long cables and additionally provides 40 dB signal gain. The preamplifier has a noise level of $<3\,\mu V$ and together with the thermal noise from the piezoelectric element, the total noise level is $<7\,\mu V$ referred to the preamplifier input.

In applications where absolutely maximum output signal level is desired from the transducer and where frequency information is irrelevant, resonance transducers such as Types 8313 and 8314 are employed. Type 8313 has its main resonance at about 200 kHz while Type 8314's resonance frequency occurs at about 800 kHz. Because of the very high sensitivity of the 8313 (typically 60 dB re. $1\,V/ms^{-1}$) it is ideal for the majority of AE measuring applications. The 800 kHz resonance transducer Type 8314 will normally be used to avoid interference from low frequency noise which can occasionally give problems up to 300 to 400 kHz, overloading the input of the preamplifier following the transducer.

### Acoustic Emission Preamplifier Type 2637



This low-noise voltage preamplifier is designed so that it can be mounted close to the AE Transducers Types 8313 and 8314 to avoid signal attenuation due to long connecting cables. Four 4,3 mm dia. holes permit the amplifier to be fastened down if required. The preamplifier circuitry, which is similar to that employed in the Broad-Band Transducer Type 8312, provides a fixed gain of 40 dB with negligible noise. System noise level is in practice determined by the transducer and is typically 2 to 3 $\mu$V referred to the input of the preamplifier.

The frequency characteristic of the preamplifier can be altered to suit the AE transducer with which it is used. The components determining the frequency characteristics are mounted on interchangeable plug-in circuit boards, three of which are included with the 2637.

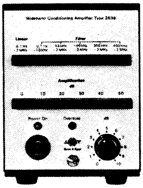
1. A 200 kHz octave bandwidth filter for use with Resonance Transducer Type 8313

2. A 800 kHz octave bandwidth filter for use with Resonance Transducer Type 8314

3. A board to provide a linear frequency range of 10 kHz to 2 MHz. This facilitates the use of other AE transducers and also piezoelectric accelerometers which may be used to detect acoustic emission at their resonance frequencies.

### Wideband Conditioning Amplifier Type 2638

Type 2638 is a general purpose AC signal amplifier covering a frequency range from 0,1 Hz to 2 MHz. It is equipped with facilities which make it especially suitable for amplifying and conditioning signals from the B & K acoustic emission transducers prior to analysis by the AE Pulse Analyzer Type 4429. The 2638 is also equipped with a signal detector enabling a simplified form of AE activity measurement to be performed in connection with a DC recorder.



Amplifier gain is selected in 10 dB steps by means of a pushbutton and in 1 dB steps by a selector knob, giving an overall gain of 60 dB in 1 dB steps.

This ability for fine adjustment of signal level is particularly useful in conjunction with the AE Pulse Analyzer Type 4429. It enables the amplitude and noise level of the AE signal to be accurately adjusted in accordance with the four fixed threshold levels in the analyzer input.

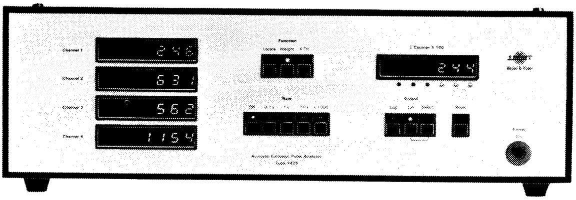
The frequency range of the 2638 is adjustable so as to avoid possible interference with AE signals by low frequency electrical noise and mechanical vibration. The upper frequency limit is normally fixed at 2 MHz while the lower limit can be pushbutton selected to either 50 kHz, 100 kHz, 200 kHz or 400 kHz according to the AE transducer used. Because the 2638 is also intended to serve as a general purpose amplifier for sound and vibration signals, a linear response setting covering the range 0,1 Hz to 2 MHz is provided. However a 10 kHz low-pass filter is additionally provided for use with piezoelectric accelerometers where it is normally desirable to limit the high frequency response to the linear portion of the accelerometer response curve.

Both AC and DC outputs are provided. The AC output feeds the AE Pulse Analyzer Type 4429 which facilitates AE pulse area measurements, four channel measurements and location of AE sources.

### Acoustic Emission Pulse Analyzer Type 4429

The AE Analyzer Type 4429 introduces an improved evaluation technique which results in close proportionality between the degree of AE activity detected on the surface of the specimen and the AE count indicated by the analyzer.

The 4429 accepts up to four AE transducers connected to the four separate counting channels. These four channels are used in different ways according to which of the three operating modes ("Weight", "Four-channel" or "Locate") is chosen.



In the "Weight" mode the AE signal from a single transducer is analyzed using all four channels of the 4429. The time during which the signal level exceeds four preset trigger levels having an amplitude relationship 1, 2, 4 and 8 is measured and, in effect, multiplied (weighted) by the amplitude difference between these levels. This results in a measured value which bears close proportionality to the area under the level versus time curve of the AE signal.

The AE count accumulated in each channel is displayed on four 7-digit LED displays and the sum of counts in the individual channels, which represents the accumulated area under the AE curve, is shown in the Σ display.

Changes in the degree of AE activity with respect to time can be displayed and recorded by selecting the "Rate" function which reads out the total count accumulated during a selected time period. Counts per 0,1 s, 1 s, 10 s, 100 s, 1000 s and 10 000 s are selectable.

In the "Four-Channel" mode the 4429 makes an approximate AE count which is similar to the traditional "ring down count" method. Because only one threshold level is used in this mode, the 4429 allows counting in up to four separate measuring channels simultaneously.

Operation in the "Locate" mode enables the source of a burst of AE activity to be localized to a particular small area.

A BNC socket on the rear panel carries a DC voltage having a level representing the figure displayed in the sum (Σ) display.

In conjunction with a graphic recorder (e.g. types 2306, 2307, 2309) the analogue output enables plotting of cumulative AE activity ,or if the "rate"function is selected the degree of AE activity with respect to time.

Finally the output of the four counter channels can also be conveyed via the standard IEC interface built-in the 4429 (a feature especially useful for on-line localization).