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INTRODUCTION TO ACOUSTIC EMISSION

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16. Abstract

Typical acoustic emission signal characteristics are described and techniques which localize the signal source by processing the acoustic delay data from multiple sensors are discussed. The instrumentation, which includes sensors, amplifiers, pulse counters, a minicomputer and output devices is examined. Applications are reviewed.

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INTRODUCTION TO ACOUSTIC EMISSION
Fundamental Considerations

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In recent years in the most advanced industrial countries (and in minor degree in Italy), industrial applications of non-destructive testing (NDT) based on acoustic emission (AE) have received increasing consideration. We will present below the fundamental characteristics of this new technical procedure. */23

WHAT IS AE?

We define as AE in a material the rapid and localized release of small amounts of elastic energy which occurs after specific microstructural processes have taken place.

Among the microstructural processes which can occur in materials, the following cause specific generation of AE:
- o processes forming plastic deformation zones (dislocation movement);
- o crystalline phase transformations;
- o fractures from microinclusions;
- o intragranular and intergranular fractures (associated, for example, with nucleation and with formation of microcracks);
- o abrupt separation of microstructural components (microinclusions, foliations, crystalline grains) of the surrounding matrix;
- o microsliding (for example, between the sides of fatigue cracks).

The elastic energy released in a single AE event can be extremely different, according to the particular microstructural process of origin. As an indication, variations may range from nanoerg (10^{-9} erg) to erg (1 erg corresponds to the kinetic energy of a steel ball of 1 mm radius and progressing at a speed of 7.8 cm/sec).

*Numbers in margin indicate pagination of foreign text.

The material is tested by placing on the surface of the item a suitable number of AE sensors. The locations where these sensors are applied are usually selected without knowing where the possible defects occur. The vibrational perturbation caused by the AE event at the source point reaches the various sensors after going through a complex propagation process, which usually causes a deep modification of the vibrational perturbation itself. Most metallic structural materials are good conductors for sound and ultrasound, at least up to frequencies of the order of 1 MHz. This permits us to achieve an effective reception of large volumes of material with few sensors, and is one of the largest advantages of AE-based NDT procedures, which do not require any local inspection techniques. The latter are always tedious and subject to possible errors.

In general, source-sensor distances of a few meters on the item to be tested are acceptable. For longer distances, there is the risk that the fraction of vibrational energy released by the AE event and effectively perceived by the sensor is too small and may have lost during the long propagation process some of the characteristics which are required for NDT utilization.

One cannot guarantee that all defects present in the material with dimensions higher than a certain value will produce AE during test stress. "Advance" microstructural processes of defects (and therefore AE generation) are more strongly related, according to fracture mechanics, to the actual conformation of the defect surface and to factors which intensify stresses occurring at their "points", rather than to the dimensions of the defects. We have to underline, however, that for test stresses of adequate intensity /24 and suitable type, it is nearly certain that the most dangerous defects, and especially planar defects (such as fatigue and stress corrosion cracks) generate AE during the test, and are therefore detectable. In this case as well, however, the characteristics of AE phenomena do not provide information on the dimensions of the defect which cause them.

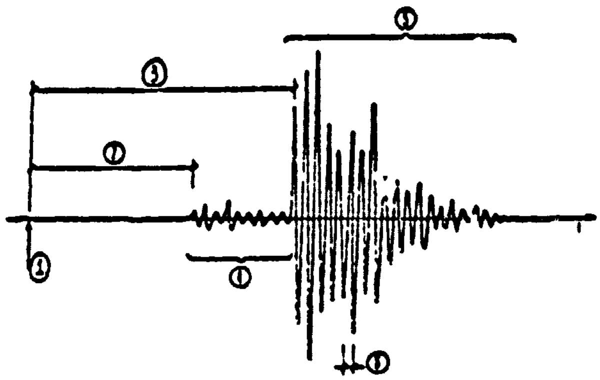

Figure 1. Typical AE pulse signal:
1) instant during which AE occurs; 2) propagation time of longitudinal waves; 3) propagation time of Rayleigh waves; 4) longitudinal wave zone; 5) Rayleigh wave zone; 6) characteristic period of oscillation of the sensor (for example 5 μsec).

associated with microstructural processes which take place during "advance" phenomena of defects possibly present. These techniques therefore:

- o make use of passive listening;
- o detect phenomena occurring in the material at the moment in which they take place.

These techniques, therefore, can only detect "dynamic" defects. This is a limitation, but at the same time a great advantage, because phenomena which "advance" are potentially the most dangerous.

Defects which may be present in the material can produce AE, and therefore be detected. It is generally required that the material undergo first an adequate stress, repesentative of working conditions.

This state of stress of the material can be induced in the item to be tested in various ways: by application of special mechanical loads used for startup tests (pressure, force, etc.); using actual working conditions; by applying transient thermal conditions, etc.

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AE based NDT techniques are used essentially:

- o to detect the presence of possible defects in the materials of the items tested;
- o to determine the position of such defects.

This second objective is achieved by measuring the delay in the time of arrival of single pulses to the various sensors. The delay varies because the lengths of the acoustic source-sensor paths vary. The accurate measurement of these time delays, to be carried out with a precision not lower than some microsecond, provides a location for the defects which generated AE.

THE TYPICAL AE SIGNAL

The shape of a typical pulse-AE signal is presented in Figure 1. The figure shows specifically the time at which the AE event occurs inside the material, the time when the wave front of longitudinal acoustic waves (the fastest in the propagation process but with low energy content) reach the sensor, and finally the time of arrival of the wave front of surface Rayleigh waves, which carry most of the AE pulse energy. For small wall thicknesses (less than approximately 10 mm) Rayleigh waves are replaced by surface Lamb waves, characteristic of a specific layer. For these waves, contrary to longitudinal, transverse and Rayleigh waves, the velocity of propagation is not constant, but varies with the frequency and the thickness of the layer.

The AE signal in Figure 1 shows a characteristic oscillating behavior of average value equal to zero. This behavior is caused by the sensor used to detect the AE pulse; this sensor is of resonating type, to obtain maximum sensitivity. In the example shown, the resonance frequency is of approximately 200 KHz, with a corresponding oscillation period of approximately 5 μsec.

An AE signal may last frequently for a total of a few hundred microseconds. This length is explained with the presence of acoustic source-sensor paths which are longer than direct paths due to reflection; it is also explained by the low acoustic absorption of the sensitive element of the sensor.

CHARACTERISTICS OF AN AE SENSOR

Modern AE detection systems permit obtaining from a typical AE signal the following descriptive information:

- the time at which the signal reaches the sensor. This corresponds to the time at which the most important wave front (usually Rayleigh waves) crosses a suitable threshold.
- the peak amplitude of the signal or the signal energy (which is proportional to the square of the peak amplitude).
- the uphill velocity of the wave front at the time the threshold is crossed. This parameter is of interest because the initial part of the wave signal, the wave front, is most likely the least "contaminated" during the propagation process and, therefore, can provide information on the nature of the microstructural process which produced the AE.
- the length of the signal.

A common previous characterization was the count of the number of oscillations of the AE signal before going below threshold ("ring down counting"). This determination is an approximate function of the energy of the signal, but is so dependent on the dampening characteristics of the sensitive element, on the way the sensor is applied to the surface and on the acoustic source-sensor propagation process itself, that its meaning becomes ambiguous.

LOCALIZATION OF AE SOURCES /25

The localization of AE sources is based on the precise measurement of the times at which the AE pulses reach the sensors. Time delays are due only to the different paths between sources and sensors. In particular, it is mandatory that the velocity of

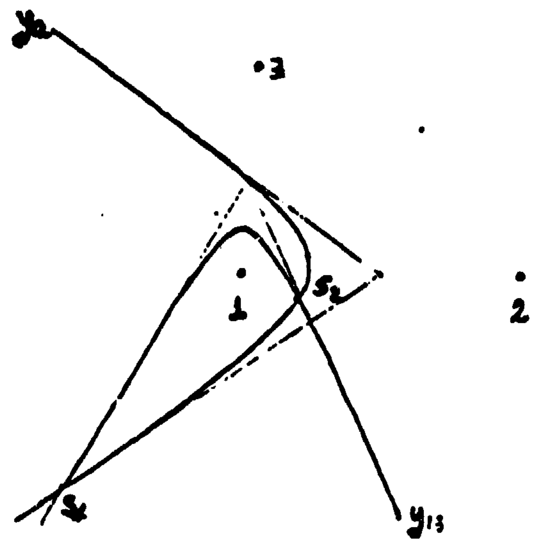

Figure 2. Localization of AE sources using the hyperbola procedure:
1,2,3 are sensor positions; the AE source of the AE event characterized by ΔT_{12} and ΔT_{13}(> is found at the intersection of the two hyperbolas Y_{12} and Y_{13}. For the case shown the possible positions, S_1 and S_2 are found for the source.

propagation of AE pulse in the material tested be the same for all directions and positions. To understand how the localization is obtained, we can refer to the case of a flat surface on which we locate three AE sensors (Figure 2). We consider at first sensors 1 and 2 where ΔT_{12} is the time delay measured for an AE pulse originating from source S. Due to the fact that a hyperbola is the locus of the points having a constant distance difference from two fixed points called foci, source S will be found on hyperbola Y_{12} having as foci the positions of the sensors 1 and 2 and defined by a distance difference from sensors 1 and 2 equal to $v \cdot \Delta T_{12}$, where v is the velocity of propagation.

The same argument can be applied to sensors 1 and 3 for which the delay ΔT_{13} was measured. Hyperbola Y_{13} has as foci points 1 and 3 and as characteristic parameter $v \cdot \Delta T_{13}$. The source is found at the intersection of hyperbolas Y_{12} and Y_{13}. As shown in Figure 2, actual intersections can be more than one (up to a maximum of four); the effective source position is identified using the signal of a fourth transducer and locating a third hyperbola on which the source is found.

Calculations for the determination of hyperbolas and related intersections, even if basically simple, are somewhat laborious, especially considering that the actual surfaces involved (pressure vessels, piping, valve bodies, etc.) are not planar but cylindrical or more complex. The calculations have to be carried out "on-line" for each of the thousands of AE events which can occur during a test. For these reasons, the use of a computer is mandatory. Instrumentation systems commercially available provide AE source localization for linear (monodimensional) or surface (bidimensional) systems.

INSTRUMENTATION FOR AE MEASUREMENT AND CHARACTERIZATION

The sequence for AE measurements includes:

o an AE sensor.

An AE sensor can be equated to a very sensitive ear, applied carefully to the surface of the item to be listened to. Its typical dimensions are a cylinder with a radius of 2 cm and a height of 4 cm. Piezoelectricity is the phenomenon utilized by the transducer converting AE into electricity.

o a preamplifier

This electronic device, to be located at a distance of a few meters from the transducer, carries out the first amplification of the extremely weak transducer signals, permitting their transmission to longer distances (hundreds of meters).

o an amplifier

The total maximum gain of a typical amplification sequence (preamplifier + amplifier) is 10^5.

o a pulse counter

This device, whose output can be connected to a paper recorder, counts AE pulses higher than a predetermined threshold value.

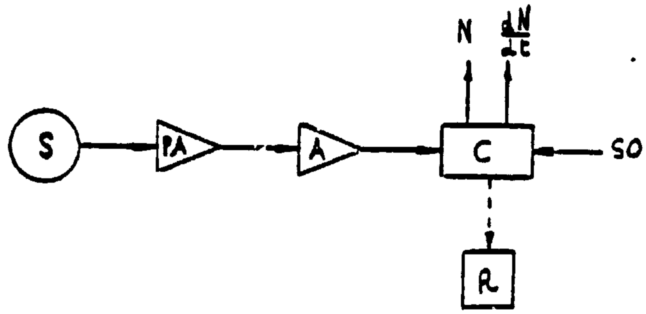

Figure 3. Single channel instrumentation sequence for AE measurement:
S = AE sensor; PA = preamplifier; A = amplifier; C = threshold (SO) counter; R = potentiometric paper recorder; N = number of AE events.

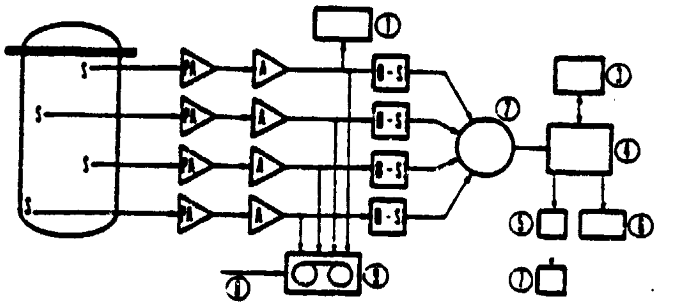

Figure 4. Instrumentation used to localize AE sources during hydrostatic tests of pressure vessels
E = AE sensor; PA = preamplifier; A = amplifier; D.S. = discriminating device; 1--acoustic monitor; 2--ΔT measurement module; 3--teletype; 4--minicomputer; 5--display; 6--cassette recorder; 7--hard copy; 9--test pressure; 9--magnetic multi-track analog recorder

The purpose of this instrumentation is to detect and count above-threshold AE events, without performing any further analysis.

The localization on surfaces of AE sources requires a much more complex instrumentation system, composed, as mentioned above, of at least four reception lines and very often of some tens of lines, with a device for ΔT measurement, a minicomputer with input and output units for source location for data handling, storage and analysis, and for presentation of the results (Figure 4).

NDT APPLICATIONS

The most established NDT application is the testing, using AE, of vessels, piping, valve bodies, etc., during pressure tests (or equivalent mechanical tests), for certification or recertification. Various groups are preparing at present operating standards for this test (an ASTM standard has already been formulated). There are many interesting AE applications to on-line surveillance of important structures and components of industrial plants. This type of application makes maximum advantage of the pecular AE characteristic of being produced at the same time as the microstructural phenomena of the materials which one wants to detect. Among degradation processes of structural materials which are effectively detected by AE, specific mention should be made of nucleation and advancement and propagation of fatigue and stress corrosion cracks. The following important applications have been carried out in this field:

- major civil engineering structures (bridges, dams);
- offshore platforms;
- vital components of chemical, petrochemical and nuclear plants (pressure vessels, piping segments, valves);
- components of electrical plants (transformers, insulators, switches);
- aircraft structures.

An AE-based NDT test which is receiving widespread diffusion is on-line testing of welding processes (tungsten inert gas, MIG, electron beam, spot welding, etc.). Possible welding defects, such as inclusions and cracks, generate during the cooling phase a strong AE, and can therefore be readily detected and eliminated. This test often requires a relatively simple instrumentation system with two or three reception channels which can localize AE sources on-line.

AE procedures have been applied not only to the diagnostic NDT of materials, but also to other processes, such as loss of pressure fluids from small moving cracks, sliding of parts in relative motion and metallic impacts. Considerable experience has now been collected, and various instrumentation systems for the most disparate applications, from fast detection of fluid leaks to the monitoring of mine tunnels and incipient slides, are now commercially available.