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WHY AND HOW ACOUSTIC EMISSION IN PRESSURE VESSEL FIRST HYDROTEST

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SYNOPSIS

AE monitoring during pressure vessel first hydrotest has reached a good industrial maturity. In this paper the main advantages obtained performing this type of examination are considered.

The characteristics and performance of the AE instrumentation to be used for a correct test are illustrated. The main criteria for AE source characterization (location, typical AE parameters and their correlation with pressure value), the calibration and test procedures, are discussed.

The ndt post-test examinations and laboratory specimen experiments are also outlined. Personnel qualification requirements are finally indicated.

1. INTRODUCTION

An extraordinary variety of Acoustic Emission (AE) applications have been suggested in twenty years of research and development.

Only few of them have reached industrial maturity.

AE monitoring of pressure vessels during hydrotest is a well proven application but, owing to loss of AE activity due to "Kaiser" effect, only AE examination during the first hydrotest has been intensely investigated.

The accumulation of experience and data allowed to obtain a considerable progress in the development of instrumentation systems. Multichannel and multiparameter equipments are available and sophisticated analyses may be performed. High sensitivity and performance instrumentation prototypes were constructed, for instance, in the frame of CISE-ENEL programmes in the AE field.

In addition, the great number of performed AE workshop hydrotest (40 were carried out by CISE on chemical and electrical plant components: reactors, towers, storage tanks, Y junctions and segments of penstock water pipes, spherical pressure vessels of hypercritical thermal power plants, a BWR pressure vessel (1-6), test facilities for nuclear reactor coolant pumps, etc.), has permitted a strong increase in the capability of AE technique to get insight into the flaw evolution process and therefore making hydrotest by AE a more and more useful examination.

On these bases, many advantages may be envisaged in AE monitoring during first hydrotest, provided that the examination is correctly carried out.

2. WHY AE IN FIRST HYDROTEST

The AE auscultation of pressure vessels during hydrotest is contextually carried out with vessel pressurization and therefore no delay and interference with working schedule is to be expected.

The method provides a one-shot picture of the AE sources producted in structural material of 100% of the vessel volume during load application.

2.1. Identification of Evolving Flaws

A complete location map of the emitting flaws is provided pointing out the positions on the wall surface to be verified by post-test usual or non conventional ndt techniques. Preexisting flaws revealing evolution under stress or the onset and growth of new defects occuring during hydrotest may be detected (cracks, disbonding and crushing of slugs, disbonding of cladding seams). Zones where loose parts are bending and frictioning, yielded areas, repairs, plate split ends are also evidenced. Finally, the distributions density of plate segregations is generally well measured giving and indication of materials quality.

Through the measurement of some significant parameters (concentration, count rate, amplitude, duration of the AE events of the located sources) and their correlation with the load or the local stress value, some information about characterization and evolution of detected flaws may be also inferred.

2.2. Failure Prevention

An early alarm before failure may be obtained by AE monitoring.
In order to check the actual capability of AE to prevent catastrophic rupture special experiments were carried out by CISE:

- low temperature (-40°C) tests were made on two through thickness notched vessels pressurized up to failure. AE sources near the tips of the groove were detected very early. With pressure increase AE became more and more intense invading more extended zone around the groove.
- a reduced scale vessel was monitored by means of AE up to its burst. Many AE events occured during the test. However, the presence of acoustic pulses produced by the use of a huge pump masked too frequently the data acquisition. The AE sources analyses were then preferably made during hold times of the test during which AE became more and more active with the increase of load value. Four concentrated AE sources were located during the hold times of the experiment (Fig. 1a, b,c) they appeared respectively at 50%, 60%, 95% and 90% of the final burst pressure value (in Table 1 the event number for the four sources at different loads is given). The failure occured just in correspondence to the above-mentioned sources and post-rupture examination showed that a large crack propagated through a path connecting the four acoustically active zones.

A direct control of damage evolution during pressurization with a feedback on pumping speed may performed. In this connection CISE performed an experiment on a full scale vessel containing real cracks detected by ultrasonic inspection in the weld of the closure head (these welds are cut-off and the heads removed after hydrotest). The AE could be able to control crack evolution in real time giving an early indication of incipient failure before a catastrophic rupture occured. From this experiment positive and interesting results were obtained. The real time diagnosis capability of AE monitoring was confirmed because the most active AE zones were detected and located just in the positions indicated by ultrasonic examinations (Fig. 2). The increasing trends (Fig. 3) of the AE event count rate and amplitude with pressure gave a demonstration of the crack evolution prognosis capability of AE method. The AE absence during load hold times gave information about crack growth stability. On the other end, the persistence of AE activity during hold times of the test final stages indicated a certain level of instability and suggested to reduce the pressure level to be reached and to slow down the pumping rate in view of aborting the hydrotest (in this case it was not necessary).

23. Remarks

The AE auscultation is basically a symptomatic technique which identifies the presence of an evolving process under a given stimulus. Other investigations have to be made (other ndt, material properties characterization, local stress distribution evaluation, knowledge of working methods of the component under examination, etc.) in order to obtain a sufficiently complete picture of the present situation. Therefore AE cannot be regarded as a substitutive method but as a tool complementary and synergic with other evaluation techniques.

Owing to the consolidated mentality in the ndt practice (linked to the capability of ultrasonic and radiographic inspection to give the flaw sizing) and to the fracture mechanics requirements, a strict correlation between AE indications and defect dimensions is generally expected. As a matter of fact, AE is linked to the flaw growth or behaviour which in turn might depend on the original size but this is not the general case. In addition only defects which show an evolution under applied stress may be individuated. The presence of other flaws which may become active in the future during operation is not excluded.

On the other hand, AE during hydrotest gives a picture of the actual "pathologic" situation identifying flaws in evolution, and allowing to look inside the process in progress to gather useful information in order to identify the cause, the diagnosis and prognosis of a progressive damage.

On the basis of the above mentioned advantages the AE monitoring of hydrotest is a well justified and useful quality test of the pressure vessel and gives an AE initial printing map for reference data base.

3 HOW AE IN FIRST HYDROTEST

In order to conectly perform the AE monitoring of pressure vessel hydrotest and to obtain reliable results, the most suitable and reliable instrumentation system must be used. The AE proper parameters and their connection with test load have also to be measured.

3.1. AE Equipment

AE multichannel and multiparameter systems have been developed in the frame of CISE-ENEL programmes and they have been used in the monitoring of the hydrotests. They work in real time. The AEDOS (Acoustic Emission Data Overlooking System) block scheme, the most recent CISE-ENEL system, is reported in Fig. 4.

The main components of the equipment are the following:

- AE sensors. High sensitivity piezoceramic sensors working in the frequency band 150-220 kHz.
- Conditioning chain. The amplification line, one for each channel, consisting in a low noise preamplifier (40 dB gain), an amplifier (0-60 dB gain) and a discriminator - shaper unit.
- AE signal processor. This device based on microprocessors performs various measurements as: arrival time differences among the sensors (ΔT), peak amplitude, rise time and duration of AE pulses, acquisition of test parameters (in the case of hydrotest the pressure value is considered).
  A transient recorder unit may be available for pulse [illegible] and digitizing. All the data are transferred to the minicomputer.
- Minicomputer. Data General minicomputer (NOVA 3, NOVA 4 or [illegible]) have been used. The pheripherals include a dual floppy disks unit, a video display (with hard copy unit) and a keyboard. The main functions accomplished by minicomputer are data acquisition, storage and retrieval from the floppy disks unit, AE source location, data analyses, presentation of the results on the video display.
- Software packages. The software programs have the following characteristics:
  - free positioning of AE sensors on the wall surface and free grouping for ΔT evaluation (no obligation to a fixed array is required);
  - wide and free spacing between the sensors (up to 12 meters);
  - interrogation of many sensors (more than those normally required for the location). This redundancy allows a more reliable and precise location;
  - an intelligent and automatic selection of the optimal ΔT values. This feature permits an adaptation to the most various geometries and odd combination of them;

- possibility to use independent and freely positioned guards or leader sensors;
- high data acquisition rate (over 100 pulses/sec);
- real time location and display;
- flexibility to the modifications and improvements and full interactivity between operator and software.

AE sensors, conditioning chain, signal processor and software packages were designed and manufactured by CISE.

3.2. AE Source Characterization Criteria

In spite of the symptomatic characteristics of AE, several analyses may be performed on AE signals in order to understand the nature of occuring degradation process. Location of AE sources, suitable event parameters and their correlation with load value allow to gather some information about the type of the flaw and its evolution.

3.2.1. AE source selection by location

The location procedure is the most powerful method for the identification and characterization of AE sources. It allows for instance after the AE sources have been localized:

- to evaluate the concentration of AE events for any source (Fig. 5). The concentrated or dispersed source distribution gives useful information on flaw type (for instance crack or plate segregations);
- to assign AE activity to specific zones of the components giving the possibility to understand the origin of the acoustic phenomena (friction between component surface and the supports, bending in correspondance of the leg or skirt welds, friction or impact of "internals" against the vessel wall, repairs, badly welded plates, scale disbonding, etc.);
- to discriminate AE produced by crack evolution from AE due to the bulk material surrounding a cracked zone;
- to distinguish between a distributed slug disbonding or crushing from a concentrated flaw growing in a weld seam;
- to visually follow the extension of large cracks during load variation (7) (Fig. 5);
- to reject spurious signals (electrical spikes, pulses due to the loose or external part impacts, or bolt tightening);
- to reject AE events or pump operation acoustic transients generated outside the monitored area.

3.2.2. AE parameters

Considerable information is contained in the AE event depending on the evolution process in progress. Unfortunatly a loss of information occurs along the path AE source - AE sensor (which may be of several meters) due to attenuation of AE burst in the material (high frequency cut off) and to the sensor frequency band (broad band sensors, on the other hand, usually exibit a reduced sensitivity).

However a part of the original information content is preserved and several analyses may be carried out on the located events. The analysis techniques implemented and applied by CISE during its experiments in laboratory and on site for each identified and significant AE located source allow the following examinations:

- total events and event count rate;
- calculation of the concentration values of the located events;
- event amplitude and energy spectra;
- event rise/time and duration distributions;
- statistical time distribution of the events.

Some general observations may be deduced through CISE experience about the capability of the above-mentioned parameters to get insight in understanding the occuring phenomena:

- high concentration values in a welded zone represent a convincing indication of the onset of serious flaw evolution;
- the appearence of high energy pulses in the amplitude spectrum is a symptom of progressive deterioration of a damaged zone especially in the final stage of crack evolution;
- a combination of high count rate, high concentration and amplitude gives an important alarm of dangerous situation;
- the presence of AE pulses of long duration may be connected with friction phenomena;
- short rise times, incompatible with the sensors frequency band, are due to electrical spikes or to tails of high intensity pulses of mechanical origin.

3.2.3. AE parameters versus load

The correlation between AE activity and characteristics and the values of test stimuli applied to the component gives a considerable contribution to the interpretation and characterization of AE phenomena.

Many relationships have been attempted. However for real time experiments it is necessary to look for the most important correlations which may be symptoms of serious damages including catastrophic failure. For this reason CISE examines in real time the following bahaviours of located sources:

- AE activity (count rate) and high amplitude event number vs. load. Special attention is devoted to high concentration sources located in structurally important zones of the component (i.e. circumferential and longitudinal welds, nozzle welds, overstressed zones, etc.);
- the saturation phenomena in count (plateau), if they occur, probably linked to pile-up process in a microcrack array;
- the presence of AE activity during hold times of the test. This fact indicates a certain level of instability and may be an alarm of dangerous degradation which can suggest to decrease the pressure value, to slow down the pumping rate and in some cases to stop the test. Decay time ("quenching time") of this anomalous AE must be carefully examined in order to take decisions on the test continuation.

Many other correlations may be studied off-line in order to better characterize AE sources. They are described in more specialized papers.

3.3. Calibration and test procedures

In the frame of CISE-ENEL programmes a special procedure has been prepared for penstok Y junction first hydrotest. The main lines of this procedure are outlined here; they are carried out through subsequent steps in order to minimize the interference with workshop time schedule.

3.3.1. Preliminary study and laboratory planning of the test

This step is concerned with the definition of test details on the basis of drawings, documents, agreements with the customer (in some cases an on site investigation is necessary). This action includes: AE monitoring phase definition (depending on the scheduled pressurization procedures), number of AE sensors and choice of their position, calibration procedure set up, measurement and analysis time schedule preparation.
This step includes also the computer programs set-up, that is the input of sensors coordinates and parameters for data analysis and graphic representation of output results.
AE sensors are then selected and intercalibrated: their sensitivity must be high and comparable within few dB.

3.3.2. Sensors preamplifiers and cables positioning

The sensors, usually less than 48, according to the vessel size, are mounted on the outer vessel surface. A reliable acoustic coupling ia assured by magnetic devices (rather powerful) and a special glue. A preamplifier is set very close to each sensor (within 1 meter) and connected to junction box. Through a multiwire cable (root), the signal is conveyed from the junction box to the measurement station (a van housing the AE measurement and analysis system) parked in a safe area.

3.3.3. Connection to the AE instrumentation system

After cable positioning the detection channels are connected to the instrumentation system located into the van.

3.3.4. Calibration measurements

After an accurate check of the instrumentation system, calibration measurements are performed by means of artificial AE sources, mainly to verify the correct performance of source location procedures in every part of the monitored area.

3.3.5. On-line measurement and analysis of AE during hydrotest

When the calibrations have been completed the hydrotest can be started together with AE monitoring. During the various pressure steps AE data are collected and, under the operator control, it is possible to process in real time the data related to the most active areas. A permanent record of all the data useful for location and classification of AE sources is available on floppy disks for future analyses.

3.3.6. Off-line AE data analysis

Further analyses are carried out on site on recorded data immediately after the pressure test to identify and classify each significant source.

3.3.7. Classification of AE sources

The analyses lead to classification of AE following the criteria defined through the accumulated experience on the same type of component. The responsible of the hydrotest is immediately informed on the possible existence and location of hazardous AE sources so that a control with traditional NDT techniques can be made.

3.4. NDT Post Test Examination

The AE localized sources are always pointed out to the customer for post test non-destructive evaluation following the procedures of ASME codes. By visual inspection some parts are often clearly identified as cause of AE source. These parts are also examined by dye penentrants and magnetic methods in order to verify the absence of any surface crack. The other AE sources located on pressure vessel and welds (their grading is always made), are carefully inspected by ultrasonic examination or, if necessary, by radiography.

3.5. Specimen Tests

Laboratory measurements to characterize the microstructural processes originating AE have to be made during tensile and fracture mechanics tests (8,9,10).

In particular for AE monitoring during pressure vessel hydrotest the characterization of AE associated to the process of subcritical crack growth in structural steel is required.

To this aim CISE performed several measurements on notched LT, TL, ST oriented 1 CT specimens of ductile steel during fracture mechanics tests. Count rate of the AE events, their peak amplitude distribution, time intervals between events were analysed.

Among the various AE parameters, peak amplitude distribution was confirmed to be the most sensitive to the crack growth.

3.6. Personnel Qualification

The EA monitoring of pressure vessels during hydrotest is not a simple test. Personnel qualification is therefore a real and very difficult problem. Expertise in the operation of instrumentation systems, large and deep knowledge of the AE processes and their correlation with material properties, of AE correlation with test parameters and of manufacturing methods and hystory of the component under examination, are definitely required.

Therefore a many years experience in AE workshop hydrotest has to be requested to the team performing the test. A professional profile of these skilled and expert operators has to be prepared.

4. CONCLUSION

AE monitoring during first hydrotest is an useful and well proven industrial test.

Despite its symptomatic characteristics, information on AE sources may be obtained using suitable criteria of characterization.

An incipient failure may be detected and alarm procedures may be activated. A suitable and reliable multichannel and multiparameter system working in real time is required.

The operation procedures for each type of component under examination have to be prepared.

Many years of experience in AE industrial workshop application are required for personnel qualification.

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TABLE 1 - Acoustic Emission activity during hold pressure periods

PRESSURE (bar)	ACOUSTIC EMISSION SOURCES			
	S1	S2	S3	S4
200	-	-	-	-
210	-	-	-	-
220	-	-	-	-
230	-	-	-	-
240	-	-	-	-
250	-	-	-	-
260	1	-	-	-
270	4	-	-	-
280	8	-	-	-
290	5	-	-	-
300	8	-	-	-
310	18	-	-	-
320	10	1	-	-
330	12	8	-	-
340	18	17	-	-
350	11	9	-	-
360	18	16	-	-
370	21	18	-	-
380	12	12	-	-
390	16	12	-	-
400	15	23	-	-
410	17	27	-	-
420	20	17	-	-
430	25	25	-	-
440	14	10	-	-
450	18	11	-	-
460	4	13	-	-
470	9	5	-	-
480	12	1	-	-
490	10	-	-	-
500	8	-	-	-
510	13	-	-	6
520	9	-	-	27
530	10	-	-	51
540	7	-	8	11
Failure	3	-	192	9

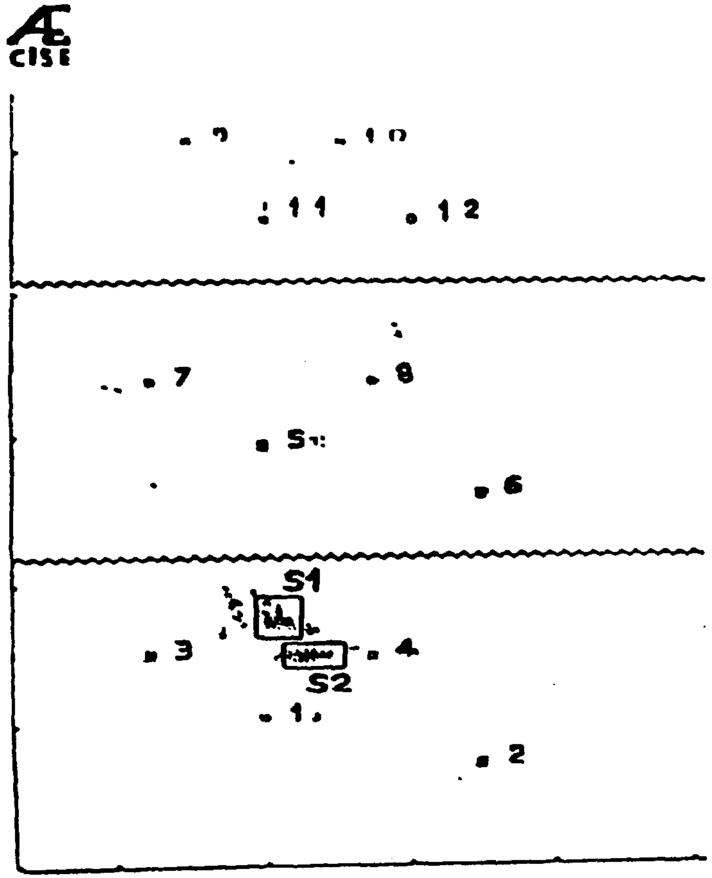


Fig. 1a - Location map of AE sources appeared during hold times before 300 atm.

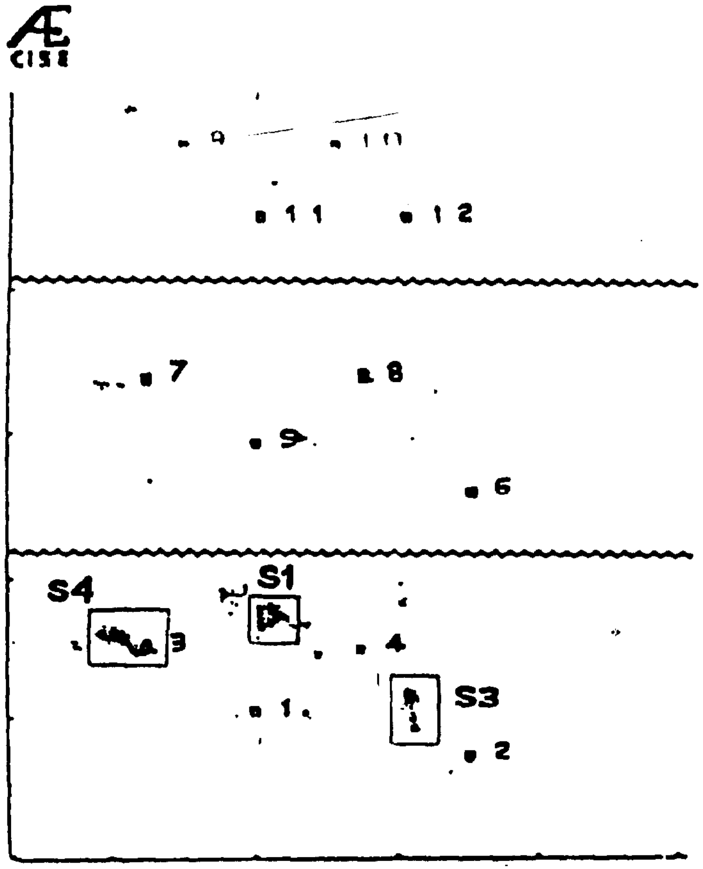


Fig. 1b - Location map of AE sources appeared during hold times in the pressure range 300 atm. - 550 atm.

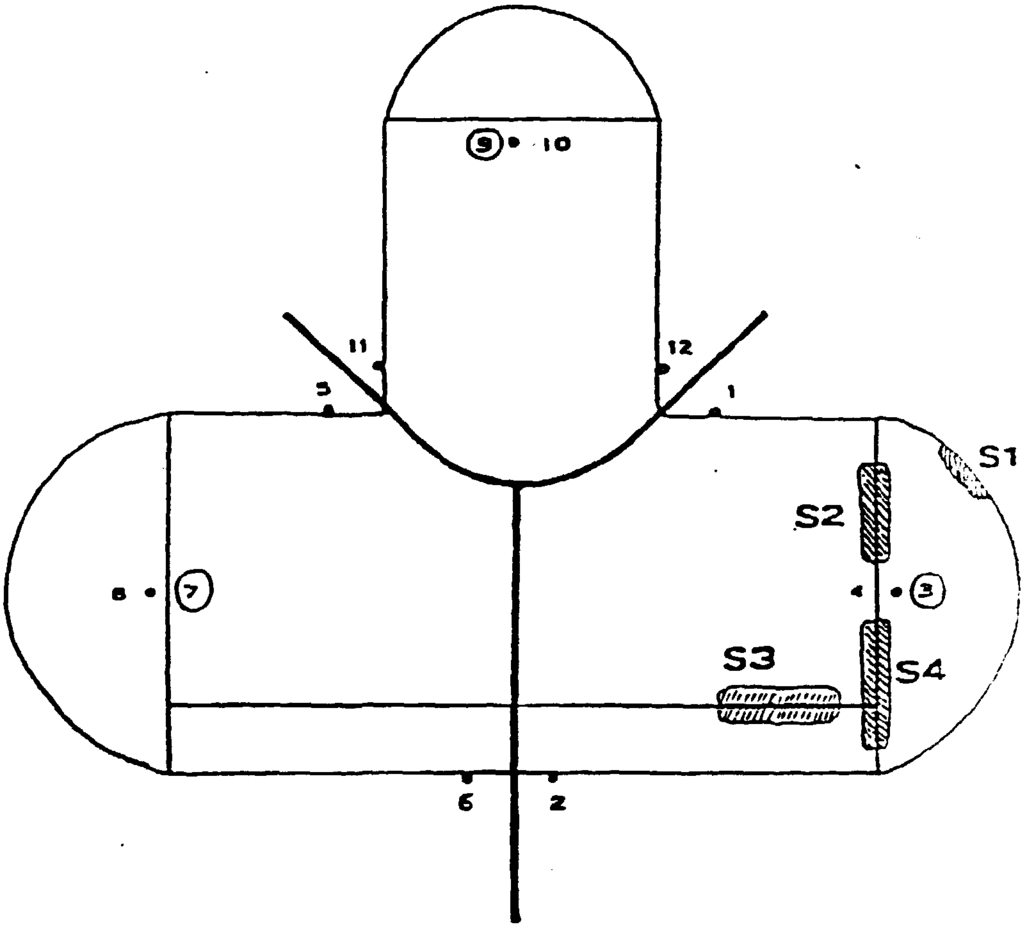


Fig. 1c - Positions of the most important AE sources (S1 - S2 - S3 - S4) on the vessel.

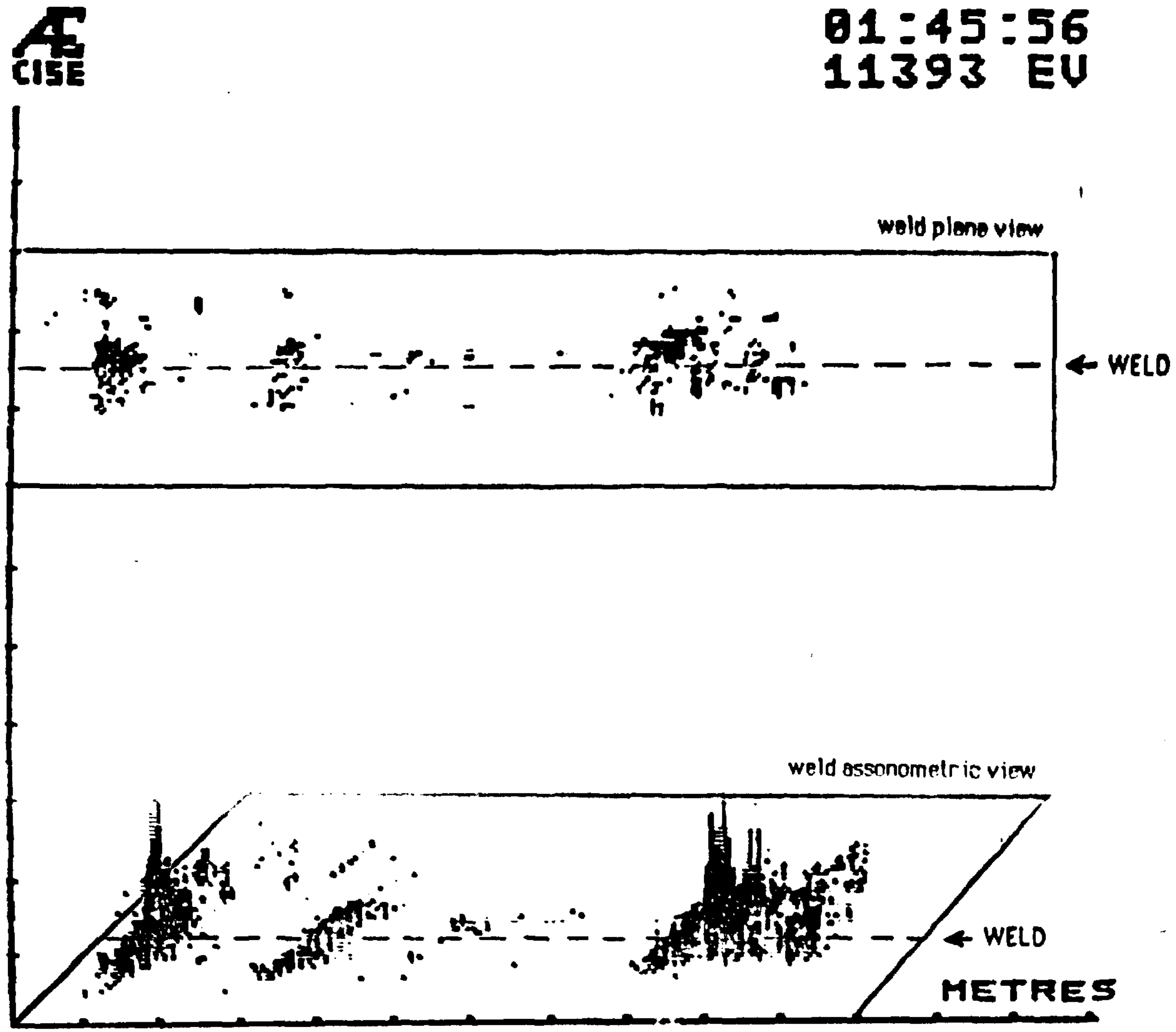


Fig. 2 - Location map of AE sources located in a weld containing real cracks.

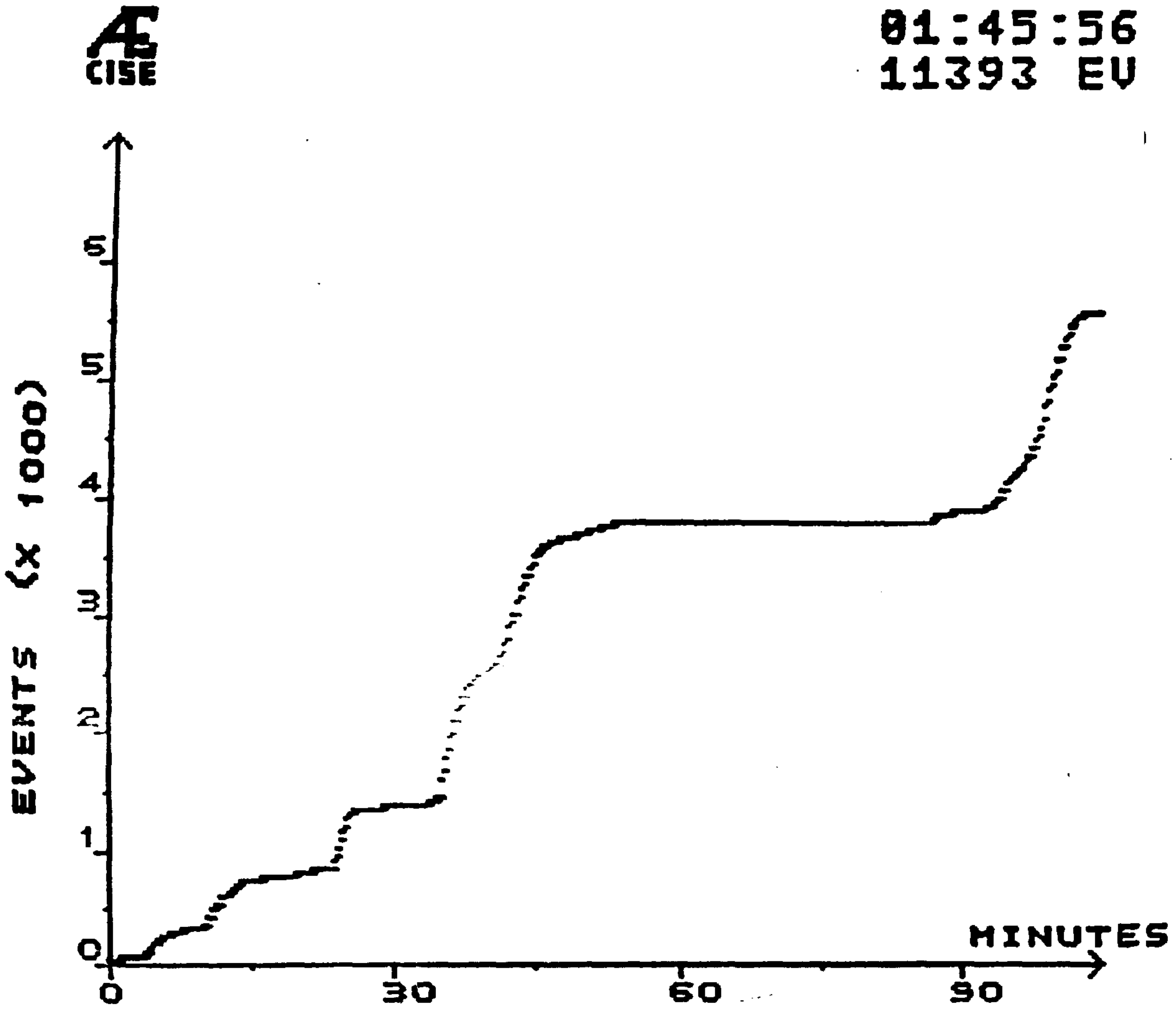


Fig. 3 - The trend of AE counting vs time (load) referred to a weld containing real cracks. The activity during hold times have to be noted.

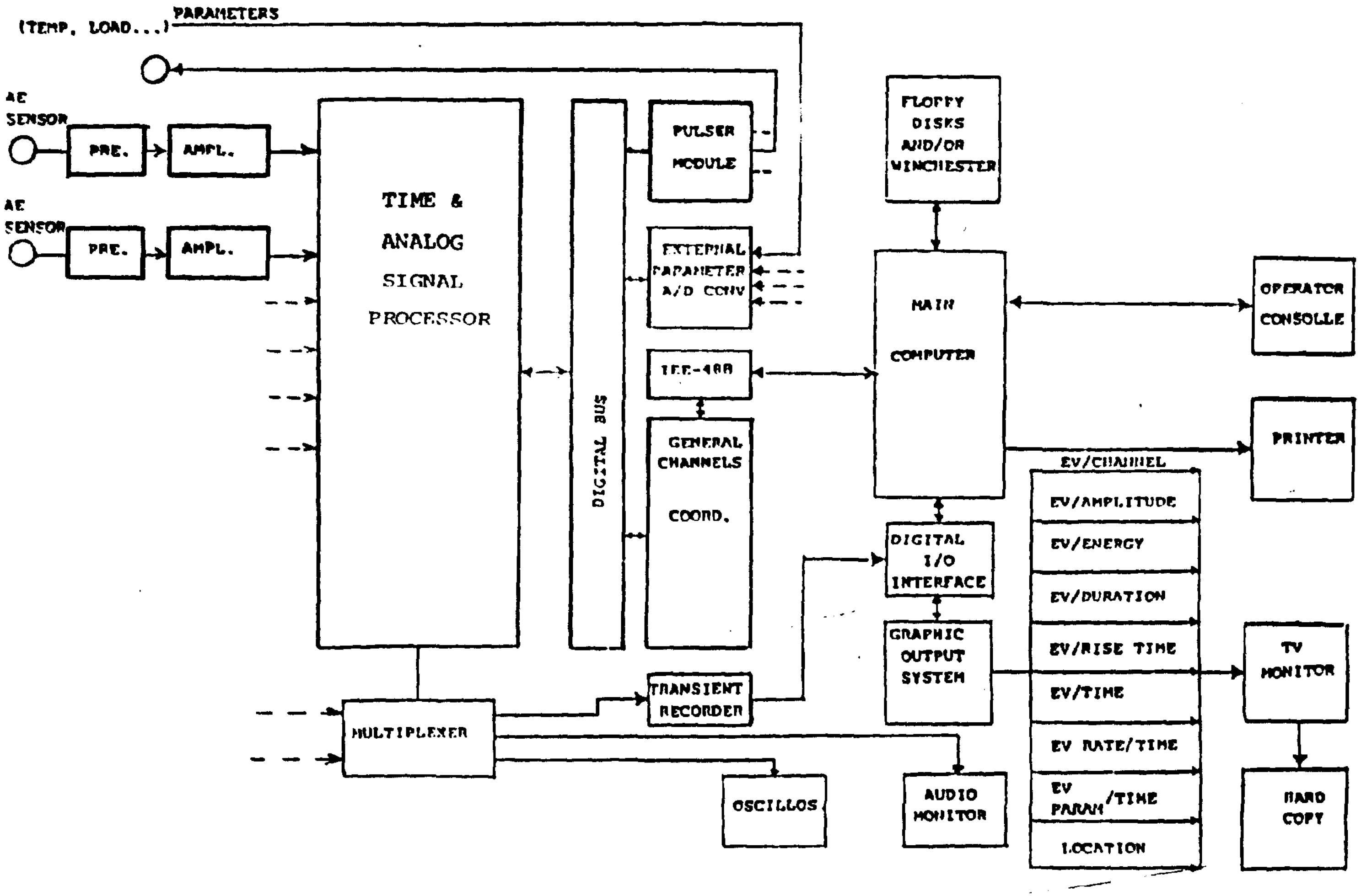
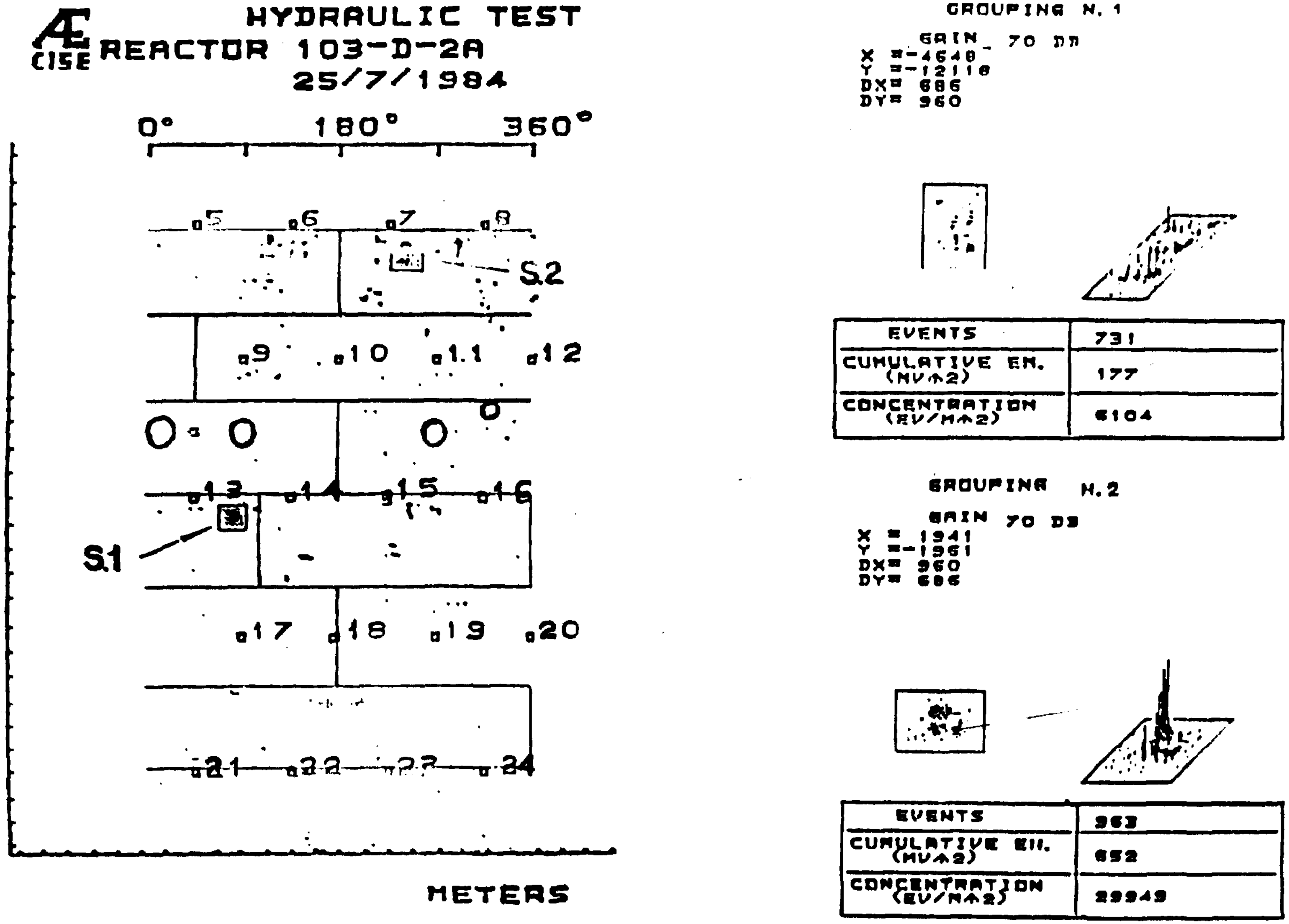


Fig. 4 - Acoustic Emission Data Overlooking System (AEDOS) block scheme.



GROUPING N. 1

EVENTS	731
CUMULATIVE EN. (MV^2)	177
CONCENTRATION (EV/M^2)	6104

GROUPING N. 2

EVENTS	963
CUMULATIVE EN. (MV^2)	652
CONCENTRATION (EV/M^2)	29949

Fig. 5 - Location map and source analysis: as an example a broad source (S_1) and a narrow source are examined.

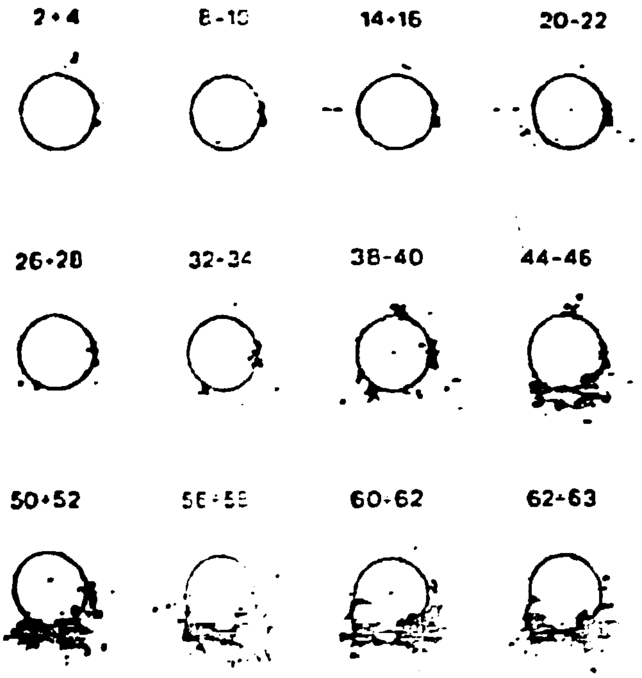


Fig. 6 - The progressive expansion of a crack during a fatigue test. The numbers indicate (in Kilocycles) the sampling intervals.