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Non-destructive testing — Acoustic emission testing — Metallic pressure equipment

Essais non destructifs — Contrôle par émission acoustique — Équipements sous pression métalliques

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 135, *Non-destructive testing*, Subcommittee SC 9, *Acoustic emission testing*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Industrial applications of acoustic emission testing for pressure equipment are expanding along with remarkable improvement of acoustic emission testing technologies. The effectiveness of any application of acoustic emission testing depends upon proper and correct usage of the acoustic emission instruments and testing techniques. In addition, the existing international acoustic emission standards lack specification of a classification system with associated recommendations for maintenance.

The purpose of this document is to provide requirements for testing equipment, testing procedures and the classification system for acoustic emission testing of pressure equipment in the field of industrial non-destructive testing. The establishment of this document can address the lack of an ISO standard for acoustic emission testing for pressure equipment. The main parties who might benefit from this document are testing organizations and owners/users of pressure equipment.

Non-destructive testing — Acoustic emission testing — Metallic pressure equipment

1 Scope

This document specifies an acoustic emission testing (AT) technique for metallic pressure equipment and the classification and evaluation of results.

This document applies to acoustic emission (AE) detection and monitoring of active sources of newly manufactured and in-service metallic pressure equipment.

This document does not apply to leak detection and in-service monitoring using AE.

This testing method is not intended to be a stand-alone method for testing and evaluation of the pressure equipment. Other non-destructive testing (NDT) methods may be used to verify and supplement the AT results.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 12714, *Non-destructive testing — Acoustic emission inspection — Secondary calibration of acoustic emission sensors*

ISO 12716, *Non-destructive testing — Acoustic emission inspection — Vocabulary*

ISO/TR 13115, *Non-destructive testing — Methods for absolute calibration of acoustic emission transducers by the reciprocity technique*

EN 14584:2013, *Non-destructive testing —Acoustic emission testing — Examination of metallic pressure equipment during proof testing — Planar location of AE sources*

EN 15495, *Non-destructive testing — Acoustic emission — Examination of metallic pressure equipment during proof testing — Zone location of AE sources*

EN 13477-1, *Non-destructive testing — Acoustic emission — Equipment characterisation — Part 1: Equipment description*

EN 13477-2, *Non-destructive testing — Acoustic emission — Equipment characterisation — Part 2: Verification of operating characteristic*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12716 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
acoustic emission testing
AT
testing of a test object during controlled stimulation using acoustic emission instrumentation to detect and analyse sources of acoustic emission

3.2
acoustic emission source
AE source
spatial element in the material where transient elastic waves are generated by the release of energy

3.3
acoustic emission source location
AE source location
determination of the spatial position of an *AE source* (3.2) at the test object based on the arrival time measurement using an array of sensors

Note 1 to entry: Several approaches to AE source location are used, including zonal location, computed location and continuous location. The spatial element can be represented by one or more location clusters in planar or linear location when using computed location method based on time difference or by a location zone when using zone location

3.4
activity of acoustic emission source
activity of AE source
total number of AE events obtained from one or more location clusters or zones assigned to one AE source at a certain spatial area of the test object

3.5
intensity of acoustic emission source
intensity of AE source
characterization of the *AE source* (3.2) by using intensity related parameters from one or more location clusters or zones assigned to one AE source at a certain spatial area of the test object

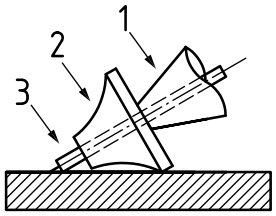
Note 1 to entry: Intensity of AE source for burst related parameters are, e.g. peak amplitude, energy, ring-down counts

3.6
active discontinuity
discontinuity which is generating transient elastic waves under controlled stimulation

3.7
pressure equipment
steam boilers, pressure vessels, piping, safety valves and other components and assemblies subject to pressure loading

3.8
Hsu-Nielsen source
device to simulate an AE event using the fracture of a brittle graphite lead in a suitable fitting

Note 1 to entry: Device given in Figure 1



Key

1	pencil
2	guide ring
3	graphite lead
hardness grade	2H
diameter	0,5 mm
length	3 mm ± 0,5 mm

Figure 1 — Hsu-Nielsen source

3.9
acoustic emission detectability parameter
K_{AE}
difference between the evaluation threshold and the system testing threshold in units dB

4 General principles

The main purpose of AT on pressure equipment is to detect and to locate AE sources within the volume or at the surface of the parent metal or welds.

a) The AT shall comprise 100 % of the pressure-bearing shell. Only in exceptional cases and when not directly affecting the safe pressurization of the equipment, the AT may be limited to specific parts agreed upon with the owner/operator at the time of enquiry or order.

b) The AT shall be done during the loading process, which includes the pressure loading, load holding unloading and reloading.

c) The AE sensors shall be arranged on the surface of pressure equipment under test in order to detect the transient elastic waves released by AE sources and transform them into electric signals.

d) These electricals signals shall be conditioned and transmitted to an AE instrument for measuring, recording, interpretation and evaluation.

5 Personnel qualification

The AT shall be performed by competent personnel. In order to ensure that this is the case, it is recommended that the personnel meet the requirements of ISO 9712 or equivalent.

6 Testing equipment

6.1 Acoustic emission testing system

An AT system employs an AE instrument, AE sensors, preamplifiers, and interconnecting cables.

This combination together with mounting devices for holding the sensors forms the AT system.

All essential parts of the system shall be specified in a written AT instruction agreed between purchaser and supplier at the time of enquiry or order (see 10.2).

6.2 Acoustic emission sensors

It is recommended to use sensors in the frequency range between 100 kHz and 400 kHz.

A lower frequency range for sensors can be advantageous in case of high attenuation.

The requirements are as follows.

a) The minimum sensitivity shall be equivalent or greater than 60 dB referred to 1 V/(m·s^{-1}).

b) Sensors shall be shielded against electromagnetic interference by proper shielding practice or by differential element design, or both. The metallic case of each AE sensor shall be electrically isolated from a metallic test object.

c) The AE sensors shall be stable over the response frequency and temperature range of use, and shall not exhibit sensitivity changes greater than 3 dB over this range.

d) The verification of the sensors should be performed according to ISO 12714 or with ISO/TR 13115 when applicable.

e) AE sensors mounted on the surface of pressure equipment shall be electrically insulated from each other.

6.3 Acoustic emission signal cables

The AE signal cables connecting sensors and preamplifiers shall be shielded against electromagnetic interference. Its length shall not exceed 1 m, unless the length-depending signal loss is considered and acceptable. This may be omitted where the preamplifier is mounted inside the shielded sensor housing.

6.4 Couplant

The couplant shall aid to keep good surface motion tracking and minimum acoustic impedance transfer effect during testing.

6.5 Preamplifiers

The preamplifiers may be separate or may be mounted inside the sensor housing.

The requirements are as follows.

a) The RMS voltage of preamplifiers circuit noise shall be less than 7 µV.

b) The preamplifiers shall be stable over the response frequency and temperature range of use, and shall not exhibit gain changes greater than 3 dB over this range.

c) The preamplifiers response frequency shall match with that of the sensors, and the gain of the preamplifiers, usually 40 dB or 34 dB, shall not cause saturation of the measurement chain up to a 100 dB_{AE} signal peak amplitude.

d) If the preamplifiers are of differential design, a minimum of 40 dB of common-mode rejection shall be provided.

6.6 Power signal cables

The signal loss of cables depends on type of cable, frequency and length. The requirements are as follows.

a) The cable providing power to the preamplifier and conducting the amplified signal to the main processor shall be shielded against electromagnetic noise.

b) Signal loss shall be no more than 1 dB per 30 m of cable length.

c) With cable length above 30 m, the resulting attenuation and the voltage drop-off of the DC-supply shall be evaluated and considered in the data analysis.

d) 150 m is the recommended maximum cable length to avoid excessive signal attenuation.

6.7 Filters

The response frequency of filters in the preamplifiers and the AE instrument shall match with that of the AE sensors.

6.8 Acoustic emission instrument

The requirements for AE instruments are as follows.

a) The AE instrument shall have enough AE channels to cover the area to be tested.

b) For each channel, the AE instrument shall display and record arrival time, threshold, peak amplitude, ring-down count, energy, rise time, and duration for each hit as a minimum.

c) The individual sampling frequency of each channel for acquisition of waveforms shall be not less than 10 times the sensors' centre response frequency.

d) The measurement inaccuracy for threshold above 40 dB_{AE} shall not exceed ±1 dB.

e) The measurement inaccuracy for ring-down counts shall not exceed ±5 %.

f) The AE instrument shall be capable to process, store and display at least 20 hits per second and per channel.

g) The delay and display from the arrival of the AE hits shall not exceed 2 seconds.

h) An alarm shall occur if the hit rate exceeds the capability of the instrument.

i) A warning shall occur when the storage space runs short.

j) The measurement inaccuracy for peak amplitudes above 40 dB_{AE} shall not exceed ±1 dB.

k) The usable dynamic range shall be a minimum of 65 dB.

l) The measurement inaccuracy for energy above 40 dB_{AE} shall not exceed ±5 %.

m) The resolution of the rise time, duration and arrival time for each channel shall not exceed 1 µs.

n) The error of arrival time measurement between all channels shall be not more than 2 µs.

o) The electronic noise levels shall be equal to or below 20 dB_{AE} in the frequency range from 100 kHz to 400 kHz.

p) It is preferred that the instrument is able to receive and record also external electric signals, such as pressure and temperature. The measurement inaccuracy for the external parametric inputs shall not exceed 1 % of the full range.

q) During data acquisition, AE software shall be capable to display the following diagrams:

   1) any AE parameter versus time or load;

   2) one AE parameter versus another AE parameter;

   3) linear, planar and/or zone locations.

r) The update time for all real-time testing diagrams shall be not more than 5 s.

s) The AE analysis software shall provide functions to replay and to analyse the recorded AT data.

   1) Linear and planar location algorithms shall be provided by the AT system manufacturer. Event location in this regard is based on Δt measurements and processes the sensor positions as well as the speed of sound. Application of linear location requires at least two sensors, and application of planar location requires at least three sensors.

   2) Zone location is based on arrival sequence of channels. The event shall be assigned to the first hit sensor location.

6.9 Maintenance and verification of testing equipment

The performance of the AT system shall be verified at specified intervals in conformity with the methods provided by the manufacturer of the AE instrument, or refer to EN 13477-1 and EN 13477-2.

6.10 Pressure gauge

The requirements are as follows.

a) A pressure gauge shall be installed on the pressure equipment prior to the test. It is recommended to use a pressure gauge with valid calibration certificate.

b) The pressure gauge shall have a range that is between 1,5x and 2x the maximum test pressure.

c) The pressure reading from the control room may be used provided a printout and/or digital data, both covering the total test period, are made available.

d) The accuracy of the pressure gauge shall be within 1 % of full range.

7 On-site operation

7.1 Preparation

7.1.1 Preliminary information

a) Prior to the testing, the following shall be specified:

   1) the purpose of the test and the amount of testing, e.g. 100 % of the pressure-bearing shell;

   2) the details of the pressure equipment to be tested;

   3) the physical location of the area where the test shall be performed;

   4) the requirements for surface preparation;

   5) the acceptance criteria;

   6) the requirements of the test report;

   7) the details of qualification of test personnel;

b) The following documents for the pressure equipment to be tested shall be provided by the owner/operator before performing an AT:

   1) manufacturing documents, e.g. declaration of conformity, drawing documents;

   2) operation recording documents, e.g. operating conditions and parameters, medium, loading fluctuations, abnormal situation in operation;

   3) previous inspection and testing reports;

4) repairs, modifications and maintenance documents.

7.1.2 Site investigation

Prior to testing, a site investigation shall be carried out to find all interference factors, such as friction of scaffold, electromagnetic interference, vibration. The interference of these factors shall be eliminated or sufficiently reduced during on-site testing.

7.1.3 Preparation of acoustic emission testing instruction and record sheets

The AT instruction and record sheets shall be prepared in accordance with the AT procedure, pressure equipment and site conditions. The instrument, applicable sensors, testing place, surface conditions and pressurization cycle of the pressure equipment shall be specified.

7.1.4 Determination of the system testing threshold

The determination of the system testing threshold shall meet the following requirements.

a) The background noise of the testing environment shall be determined by lowering the system testing threshold to obtain the hit rate of not more than 1 hit per second for each and every channel.

b) The background noise measurement of newly manufactured pressure equipment and in-service pressure equipment being off-line shall be not less than 5 min.

c) For the in-service pressure equipment being on-line, the measurement shall be not less than 15 min.

d) The system testing threshold of each channel shall be higher than the background noise by at least 6 dB.

e) If the background noise level is close to AE signal peak amplitude caused by the active discontinuities in the pressure equipment, the background noise shall be reduced or eliminated, or the sensor spacing shall be reduced, otherwise it is not suitable to perform the AT.

7.1.5 Determination of the attenuation curve

The attenuation of the AE waves on the test pressure equipment to be tested shall be determined. This is necessary for determining the sensor spacing for effective detection of AE sources and recalculation of signal peak amplitude to source location.

The attenuation shall be determined away from the discontinuous structure such as manholes and nozzles using simulated AE sources.

The procedure for the correction of signal peak amplitudes with distance shall be done according to EN 14584:2013, Annex A.

If attenuation data from the same testing conditions are already available, it is not necessary to determine the attenuation again, but the attenuation data shall be indicated in the record sheets and the test report.

7.1.6 Sensor array

The requirements are as follows.

a) A sufficient number of sensors shall be mounted on the surface of the pressure equipment to enable AE signal detection and source location, according to the dimension of the equipment and the purpose of the testing.

b) The allowed maximum sensor spacing shall be determined based on measured attenuation curve of AE peak amplitude, in accordance with EN 14584 and EN 15495.

c) The spacing difference between adjacent sensors in the same triangle or square array shall be as low as possible.

d) All the sensors shall be numbered and indicated in the schematic diagram of the pressure equipment to be tested. Annex A provides guidelines for sensor placement for some types of pressure equipment.

7.1.7 Pressurization sequence

The requirements are as follows.

a) The pressurization sequence shall be established according to the purpose of AT and the real condition of the pressure equipment.

b) The communication of the AT operator with the pressurization operator shall be included in the AT instruction.

7.2 Sensor mounting

The mounting of sensors shall meet the following requirements.

a) The sensors shall be installed according to the specified sensor array. The sensors shall keep a minimum distance of 50 mm to manholes, nozzles, flanges, supports, pillars, backing plates and welds during the whole testing of the pressure equipment. For local testing the testing area shall be near but not in the centre of the sensor array.

b) The place for the mounting of a sensor on the structure shall be smooth and showing the metallic lustre. The coating can be kept when it is smooth and compacted and the determined attenuation is acceptable.

c) Efficient couplants such as vacuum grease or petroleum jelly are recommended.

d) The temperature class of the couplant shall be matched to the surface temperature of the pressure equipment.

e) Firmly fixing of the sensors with the pressure equipment shall be performed by a magnetic holding device, by an adhesive tape or other method, keeping the electrical insulation.

f) For low-temperature or high-temperature pressure equipment, AE waveguides (rods) shall be used to improve the coupling temperature of the sensor.

g) The effect of the waveguide on the attenuation and localization characteristics of the AE signals shall be determined.

7.3 Settings of the acoustic emission instrument

7.3.1 General requirements

Connect the sensors and preamplifiers with the corresponding input channels of the AE instrument by cables, turn on the AE instrument and wait until the testing equipment is in proper working condition.

7.3.2 Sensitivity check

The sensitivity of each channel shall be checked using a simulated AE source.

The requirements are as follows:

a) The simulated AE source shall be the Hsu-Nielsen source.

b) The detected peak amplitude of the simulated event shall be at a fixed distance from the centre of the sensor, and the responsive value shall be the average of more than 3 measurements.

c) The generated AE signal shall have a peak amplitude of at least 90 dB_{AE} at a distance of 50 mm ± 5 mm from the centre of the sensor.

d) The average peak amplitude of any sensor shall be within ±3 dB of the average of all sensors.

e) The sensitivity check for all channels shall be done before and after the testing. The use of an electronic pulser to check that there is no subsequent change in sensitivity, by comparison with that obtained prior to the test, is an acceptable alternative to repeating the Hsu-Nielsen source check.

7.3.3 Verification of the location system

The verification of the location system shall meet the following requirements.

a) When using the computed localization, the simulated AE source, i.e. a Hsu-Nielsen source minus the AE detectability parameter K_{AE}, shall be received at least by the minimum number of sensors required by the used location algorithm, and shall be located solely within the sensor array on the test object. The error of location shall be no more than ±5 % of the sensors spacing.

b) When using the zone location, the simulated AE source shall be received by at least one sensor in that area.

7.3.4 Intensity analysis

For the intensity analysis of Δt-based located events, the peak amplitude at the point of source shall be derived from the measured peak amplitude at the first-hit sensor and the calculated distance from the first-hit sensor to the calculated point of source as described in EN 14584:2013, Annex A.

7.4 Performing the test

7.4.1 Pressurization sequence

7.4.1.1 General requirements

The pressurization sequence shall generally meet the following requirements.

a) For newly manufactured pressure equipment, the pressurized medium shall be water or another safe medium.

b) For in-service pressure equipment being off-line, the pressurized medium shall be water, gas utilized during the process, inert gas such as nitrogen or another safe medium.

c) For in-service pressure equipment being on-line, the pressurized medium shall be its working medium.

d) The highest test pressure and pressurization sequence for AT shall be determined by the operating manual and design documents of the pressure equipment, relevant safety technical specifications, standards and contractual requirements.

e) The rates of pressurization shall be determined by the operating manual, design documents or design standards of the pressure equipment. If there is no special requirement, it shall be generally not more than 5 % of highest test pressure per minute in case of hydraulic pressurization and not more than 1 % of highest test pressure per minute in case of pneumatic pressurization.

f) If the AE signal appears continuously during the pressurization or hold period with a large number, the pressurization shall be stopped or reduced as soon as possible and the cause for the high activity of the AE source shall be investigated.

g) If the AE signal appears continuously during the hold period with a small number, the hold period shall be extended appropriately until the AE signals converge.

h) The hold period shall be terminated early if no AE signal appears within 5 min.

7.4.1.2 Pressurization sequence for newly manufactured pressure equipment

The AT of the newly manufactured pressure equipment may be carried out during the hydrostatic pressure test.

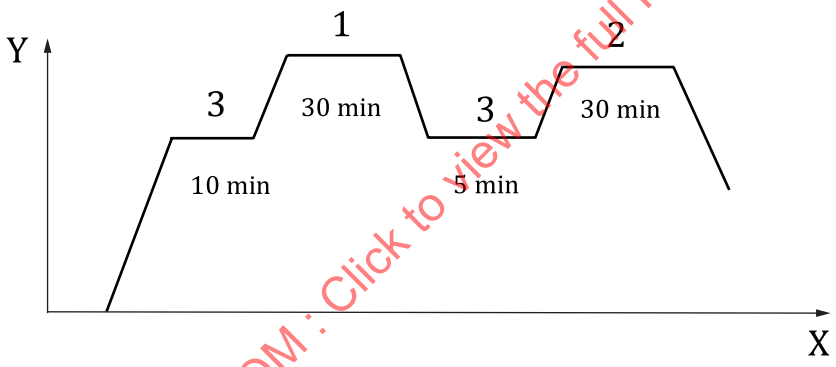
Figure 2 gives an example for the pressurization sequence for newly manufactured pressure equipment. The pressurization sequence shall meet the following requirements.

a) The AT shall start before the equipment pressure reaches 20 % of the design pressure P_D (or nominal pressure or rated working pressure).

b) The pressure shall be held at least 10 min when the pressure reaches the design pressure P_D and at least 30 min for the highest test pressure P_{T1}. P_{T1} shall be equal to the hydraulic test pressure.

c) If the first loading data indicates a possible active discontinuity or is inconclusive, the equipment shall be repressurized from P_D.

d) The highest test pressure of the second pressurization P_{T2} shall be above 97 % of P_{T1} and below P_{T1}.



Key

X time
Y pressure
1 $P_{T1,}$ the highest test pressure of the first pressurization
2 $P_{T2,}$ the highest test pressure of the second pressurization
3 $P_{D,}$ the design pressure

Figure 2 — Example of the pressurization sequence for newly manufactured pressure equipment (minimum requirement)

7.4.1.3 Pressurization sequence for in-service pressure equipment

Figure 3 gives an example for the pressurization sequence for in-service pressure equipment.

a) For in-service pressure equipment being off-line, the pressurization sequence shall meet the following requirements.

1) The highest test pressure P_{T1} shall be at least 110 % of the maximum working pressure P_W of past 12 months. The pressure equipment operator shall provide this information on basis of operational data in digital format or as print-out covering the past 12 months period prior to the date of test.

2) The AT shall start before the equipment pressure reaches 50 % of the maximum working pressure.

3) The pressure shall be held at least for 30 min when the pressure reaches the highest test pressure P_{T1}.

4) If the first loading data indicates a possible active discontinuity or is inconclusive, the equipment shall be repressurized from 50 % of the P_{T1}.

5) The highest test pressure of the second pressurization P_{T2} shall be above 97 % of P_{T1} and below P_{T1}.

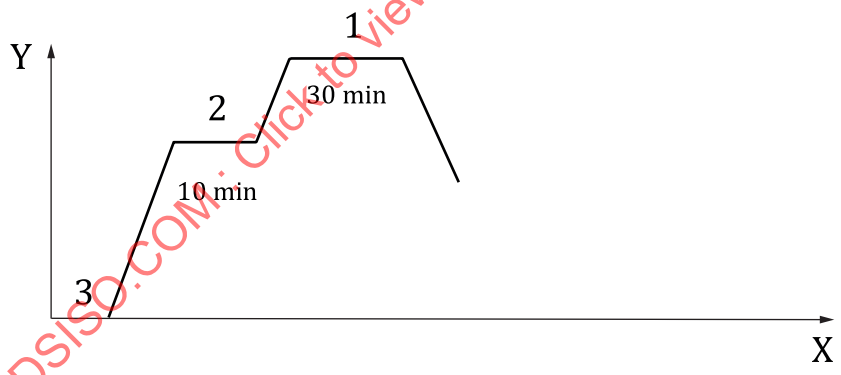
b) For in-service pressure equipment being on-line, the pressurization sequence shall meet the following requirements.

1) The highest test pressure P_{T1} shall be at least 110 % of the maximum working pressure P_W of past 12 months. The pressure equipment operator shall provide this information on basis of operational data in digital format or as print-out covering the past 12 months period prior to the date of test. The highest test pressure P_{T1} shall be lower than the design pressure P_D. If these requirements are not possible, it shall be considered to take the pressure equipment out of operation and apply the procedure described under 7.4.1.3 a).

2) The working pressure shall be reduced as low as possible at least 5 days prior to AT to the start test pressure P_{TS}.

3) The AT shall start at the beginning of the pressurization.

4) The pressure shall be held at least for 10 minutes when the pressure reaches the maximum working pressure P_W and at least for 30 minutes for the highest test pressure P_{T1}.



Key

X time
Y pressure
1 P_{T1}, the highest test pressure
2 $P_{W,}$ the maximum working pressure
3 $P_{TS,}$ the start test pressure

Figure 3 — Example of the pressurization sequence for in-service pressure equipment (minimum requirement)

7.4.2 Data acquisition and observations during acoustic emission testing

The requirements for data acquisition and observations during AT are as follows:

a) The data acquisition shall include the parameters given in 6.8 b).

b) Using software filters or graphic data display analysis methods, the non-correlated AE signals shall be separated from relevant AE signals, and indicated in the test records.

c) For AE source location clusters in computed location method based on time difference, the spatial area shall be confirmed by simulated AE sources.

d) The arrival times of AE signals shall be collected when using source location based on the time difference between channels.

e) The trend of the AE hits and/or AE events versus time shall be observed during the test.

f) For an area bristled with located AE events, it shall be checked whether there is external interference.

g) During the test, the background noise shall be monitored. Periods of obvious noise interference shall be marked.

7.4.3 On-line data analysis and stop criteria

7.4.3.1 General

In the process of AT, the AE signals shall be observed and analysed on-line for the whole duration of the test. If disturbance noise occurs during the testing, it shall be treated according to 7.4.3.2. Data observations and analysis during testing shall be performed according to 7.4.2 and 7.4.3.3.

7.4.3.2 Noise during testing

Attention must be given to the following factors that can affect the testing results:

a) injection of medium;

b) excessively high pressurization rate;

c) external mechanical vibration;

d) movement or pressure burst of internal components, tooling, scaffolding, apparatus;

e) electromagnetic interference;

f) weather conditions, such as interference from wind, rain, hail;

g) leakage.

7.4.3.3 Data analysis during testing

The trend of the AE hits versus pressure or time shall be observed during the test.

For source location based on time difference between channels, the trend of located AE events versus pressure or time shall be observed during the test. For an area with widespread located AE sources, it shall be checked whether there is external interference.

7.4.3.4 Stop criteria

A decision to stop the test shall be made in the case of increasing the activity of the AE source and/or intensity of the AE source during a loading sequence.

a) If there is a large amount of AE signals during loading, the pressurization shall be stopped and the testing shall be paused.

b) If AE signals with very high peak amplitudes appear during the testing (depends on the material and construction of the pressurized equipment), the pressurization shall be stopped and the testing shall be paused.

c) After reaching pressure hold, if AE signals are still being generated, there is a possibility of crack propagation without further loading. The pressure shall be decreased until no new AE signal is generated.

The AT operator shall investigate the reasons for these AE signals through data analysis and on-site observation. If necessary, other non-destructive testing methods may be required for clarifying the found indication. If a noise signal is identified, it shall be eliminated to continue with pressurization. If the AE signals are caused by a potential severe defect, the pressure test shall be terminated.

8 Interpretation and evaluation of AE data

8.1 General

The general requirements for interpretation and evaluation of AE data are as follows.

a) On completion of the test, data analysis and interpretation shall be performed off-line according to 8.2.

b) Classification of the AE sources of the test object shall be performed according to 8.3.

c) The results of data analysis, interpretation and classification of the AE sources of the test object shall be documented in the test report.

d) A schematic diagram of the AE sources location of the test object shall be included in the test report.

8.2 Off-line data analysis

After completing the AT, all recorded AE signals shall be processed, analysed and interpreted to perform the diagnosis of the test.

The data analysis and interpretation shall meet all the following requirements.

a) Noise signals that occur during detection shall be clearly identified.

b) Appropriate filtering methods shall be selected to filter noise signals and irrelevant AE signals.

c) The AE signals shall be analysed as a function of pressure and time.

d) The characteristic parameter distribution of the AE signals shall be analysed.

e) Special attention shall be paid to high peak amplitude AE signals.

f) The AE source location method shall be chosen according to the testing purpose: zone location, planar location or linear location.

   1) For zone location analysis, each zone covered by a sensor shall be considered individually.

   2) For linear and planar location analysis, each and every location cluster shall be analysed individually.

   3) For planar location analysis, the correction of the peak amplitude as a function of the distance shall be performed.

4) For linear location analysis, the correction of the peak amplitude as a function of the distance shall be applied depending on the testing technique and purpose.

g) The type of AE source location, shape and size of the area of an AE cluster or zone shall be determined.

h) The analysis methods with conditions such as the evaluation threshold and the testing threshold used (in dB_{AE}) that were applied for interpretation of the results shall be recorded in the final test report.

8.3 Classification of the acoustic emission sources of the test object

8.3.1 Determination of the area of an acoustic emission cluster or zone

For zone location methods, the shape and size of the area of an AE zone shall be determined from the sensor array. If there is no special requirement, it is recommended that the area covered by a sensor is the area divided by the centre line of the sensor and the adjacent sensors in the sensor array. All AE hits detected first with this AE channel are considered to be the AE events of this AE zone.

For linear location methods, a linear rating area of an AE cluster shall be defined by the maximum sensor spacing in the sensor array. The length of the rating area shall be defined based on the size of pressure equipment and testing purpose. The located AE events falling within this area shall be considered to be the AE events from this AE source area.

For planar location methods, a square or circular rating area of an AE cluster shall be defined by the maximum sensor spacing in the sensor array. If there is no special requirement, it is recommended that the length or diameter of the rating area is 10 % of the maximum sensor spacing in the sensor array. The located AE events falling within this area shall be considered to be the AE events from this AE source area.

8.3.2 Classification system for acoustic emission sources

The assessment of AE sources is based on the activity and intensity of the AE sources. The AE sources shall be assessed by a classification system consisting of four different classes as shown in Table 1. The class definition, severity degree and recommended further action also are given in Table 1 based on the risk management and safety assurance of pressure equipment during operation.

Table 1 — Classification system for acoustic emission sources

Class	Definition	Severity degree	Recommended further action	
			New pressure equipment In-service pressure equipment being off-line	In-service pressure equipment being on-line
I	Non-significant source	Not serious	Neglectable indication No further action	Neglectable indication No further action
II	Weak active source	Inconclusive	Weak indication Note for future reference	Weak indication Note for future reference
III	Active source	Serious	Obvious indication Immediate follow up with other NDT methods	Obvious indication To be prioritized for follow up with other NDT methods
IV	Very active source	Critical	Strong indication Immediate follow up with other NDT methods	Strong indication Immediate follow up with other NDT methods

For new pressure equipment and in-service pressure equipment being off-line, discovering class III and class IV AE sources shall be immediately followed up with other NDT methods before starting or restarting operation of the pressure equipment.

For in-service pressure equipment being on-line, discovering class IV AE sources shall be immediately followed up with other NDT methods in order to clarify if the pressure equipment needs to be taken directly out of service.

For in-service pressure equipment being on-line, discovering class III AE sources shall be prioritized for follow up with other NDT methods.

For all pressure equipment, discovering class II AE sources shall be noted for future reference.

For all pressure equipment, discovering class I AE sources do not need further action.

Subclauses 8.3.3 to 8.3.5 specify the allowed classification methods, at least one of these methods shall be applied.

The application of the classification methods shall comply with Table 1.

8.3.3 Classification method 1

8.3.3.1 General

Application of only one sensor on the test object does not allow arrival-time-based location analysis.

Linear location analysis shall be the preferred option where piping and small pressure vessels as well as medium-sized cylindrical vessels have to be tested under the constraint to separate different physical events according to their origin in one dimension.

Locations of AE sources shall then be reported by one coordinate, e.g., the distance to a reference point along the cylindrical axis.

It has to be noted that a limited but rather large area of the test object may be regarded as potential origin of the physical source leading to the found location results.

Planar location as defined by EN 14584 shall be used when medium and large pressure vessels have to be tested or when there is a greater need for detailed analysis to be involved in the vessel assessment (e.g. higher risk due to flammable fluid contents, high-pressure applications, poor wave propagation conditions of the vessel shell).

The assessment of these vessels shall include the determination of the location of the active sources.

The location algorithm using a system of coordinates in two dimensions shall be selected according to the shape of the test object (planar plane, planar cylindrical or spherical).

The location accuracy of ±5 % of the maximum used sensor spacing $d_{max,u}$ shall be verified by using the Hsu-Nielsen source according to EN 14584.

Application of only one sensor on the test object does not allow arrival-time-based location analysis.

8.3.3.2 Classification

The on-line assessment of the test data shall be made according EN 14584.

The specific values of EB, A1, N1, AC1, NC1, AC2, NC2, N3, Z and t_h shall be fixed from the testing organisation within the pressure equipment specific AT instruction.

The test shall be stopped in case the values N1, NC1, NC2 or N3 are reached or exceeded.

Moreover, the test shall be stopped as well in case the energy on at least one channel reaches or exceeds a value of EB and doubles in two consecutive intervals of pressurization with 5 % of the maximum test pressure.

An example for the on-line evaluation parameters is given in Table 2:

Table 2 — Example for the on-line evaluation parameters according to EN 14584 when testing a pressure vessel with a yield strength of more than 355 MPa

On-line evaluation parameters	Example values
EB	10 000 eu
A1	110 dB_{AE}
N1	5
AC1	95 dB_{AE}
NC1	5
AC2	83 dB_{AE}
NC2	20
N3	2
Z	0,1 $d_{max,u}$
t_h	5 min

The off-line evaluation parameter can be derived from those used for on-line analysis as shown in Table 3.

The classification method based on the evaluation parameters shown in Table 2 and Table 3 is given in Table 4.

Table 3 — Example for the off-line evaluation parameters when testing a pressure vessel with a yield strength of more than 355 MPa

Off-line evaluation parameters	Example values
A1*	110 dB_{AE}
N1*	3
AC1*	95 dB_{AE}
NC1*	3
AC2*	83 dB_{AE}
NC2*	10
Z*	0,1 $d_{max,u}$

Table 4 — Classification method based on on-line and off-line evaluation parameters for linear and planar location of AE sources

Class	I	II	III	IV
Criterion	None of the values N1*, NC1* or NC2*/2 are reached or exceeded	The value NC2*/2 is reached or exceeded but not the values N1*or NC1*	At least one of the values N1* or NC1* or NC2* are reached or exceeded	Stop criterion for on-line analysis fulfilled

Alternatively, a software tool for evaluation of detected AE location clusters according to their severity may be used.

Such a tool shall be able to process on-line the following parameters of each and every located event within the respective location cluster:

a) peak amplitude;

b) energy;

c) duration;

d) number of events per location cluster;

e) event rate per location cluster;

f) number of high peak amplitude signals.

For any detected location cluster, the output of the software tool, often referred to as cluster evaluation factor (CEF), is a single value within a specified severity range.

The severity range shall be structured into different AE source severity classes, see Table 5.

Table 5 — Classification method based on the cluster evaluation factor for linear and planar location of AE sources

Class	I	II	III	IV
Cluster evaluation factor CEF	$0 \leq CEF \leq a$	$a < CEF \leq b$	$b < CEF \leq c$	$c < CEF$

The values a, b and c in Table 5 shall be specified in the AT instruction by the test organisation according to the results obtained from verification tests.

The on-line evaluation criteria to stop the test shall be fulfilled if the cluster evaluation factor exceeds the value c.

If the AE test is completed, the off-line evaluation of the test data shall provide the final classification of the identified AE sources according to Table 5.

The severest AE source shall represent the condition of the test object.

8.3.4 Classification method 2

8.3.4.1 General

The area of an AE location cluster used by this method shall be carried out according to 8.3.1.

This method includes the following three steps.

a) The activity level of the AE source in the AE location cluster shall be evaluated by class.

b) The intensity level of the AE source in the AE location cluster shall be evaluated by class.

c) The class of the AE source in the AE location cluster shall be evaluated based on its activity and intensity level.

8.3.4.2 Classification

8.3.4.2.1 Evaluation of the activity level of the acoustic emission source

The evaluation of the activity level of the AE source shall be determined by the total number N of located AE events in the AE location cluster area, as shown in Table 6.

Table 6 — Evaluation of the activity level of the acoustic emission source

Total number N of located AE events	$N < N_M$	$N_M \leq N < N_S$	$N_S \leq N < N_{VS}$	$N_{VS} \leq N$
Activity level of the AE source	Weak	Medium	Strong	Very strong

The values N_M, N_S and N_{VS} in Table 6 shall be specified in the AT instruction by the test organisation according to the results obtained from verification tests.

The test shall be stopped if the total number of located AE events in the AE cluster area is equal or exceeds the value N_{VS}.

8.3.4.2.2 Evaluation of the intensity level of the acoustic emission source

The evaluation of the intensity level of the AE source shall be determined by the characteristic peak amplitude A of located AE events in the AE location cluster area as shown in Table 7.

The peak amplitude correction of the located AE events shall be applied according to results of the attenuation measurement.

The characteristic peak amplitude A of the AE source in the AE location cluster area shall be the average of the five largest peak amplitudes of all the located AE events.

The values A_M and A_H in Table 7 shall be specified in the AT instruction by the test organisation according to the results obtained from verification tests.

Table 7 — Evaluation of the intensity level of the acoustic emission source

The characteristic peak amplitude A of located AE events	$A < A_M$	$A_M \leq A < A_H$	$A_H \leq A$
Intensity level of the AE source	Low	Medium	High

8.3.4.2.3 Evaluation of classes of acoustic emission sources

The class of an AE source shall be evaluated in accordance with their activity level and intensity level, as shown in Table 8.

The severest AE source shall represent the condition of the test object.

Table 8 — Evaluation of classes of acoustic emission sources

		Activity level			
		Very strong	Strong	Medium	Weak
Intensity level	High	IV	IV	III	II
	Medium	IV	III	III	I
	Low	III	III	II	I

8.3.5 Classification method 3

8.3.5.1 General

This classification method is based on zone location using severity value and historic index. It is mainly used on large structures.

Location settings are less critical because only one sensor needs to detect an event. But this has a disadvantage, because location cannot be applied as a noise filter. For this reason, during a zone location test special care shall be taken to avoid noise and post test data filtering requires special attention.

After the test the data shall be reviewed to remove noise:

a) Periods of noise where the cause was noted during the test shall be removed.

   An example is noise from the closure of valves at the start and end of a hold period.

b) Genuine data is normally related to the pressure, noise is normally not.

   Signals caused by e.g., surge pressure, water hammer or by cooling steam tracing will continue through pressure increase and hold periods. The same holds for noise from nearby plant.

   However sometimes the data can be real even if it is not related to pressure e.g. data from stress corrosion cracking.

c) Some types of noise can be removed based on the signal characteristics.

Very short duration AE hits well above the threshold may indicate electro-magnetic interference. Very long duration AE hits may indicate mechanical noise. These hits can be used as a tell-tale to remove short periods of time from the test data. High peak amplitude data shall never be removed from the post-test unless the source is clearly not relevant.

8.3.5.2 Classification

After noise removal, evaluation of the data shall be performed per zone at the evaluation threshold.

The evaluation threshold shall be specified in the AT instruction. It depends on the material (type of metal, yield strength, heat treatment), the type of vessel and on the type of test (new, in-service, 1st or 2nd loading).

8.3.5.2.1 First evaluation step based on criteria

The first part of the evaluation is based on five criteria:

a) AE hits above evaluation threshold:

This gives an indication of the size and severity of the defective region. This criterion is particularly important for in-service vessels, where hits below the operating stress indicate the presence of significant defects. The phenomenon of hits below normal operating loads is an indication of the severity of a defect.

b) High peak amplitude AE hits:

These often indicate the presence of a growing crack.

c) AE hits during load hold:

This is particularly significant. Continuing emissions indicate continuing yield or damage due to creep or a growing discontinuity. Fill and other background noise will generally be at a minimum during a load hold period.

d) Increasing activity of AE source with load.

e) Increasing intensity of AE source with load:

Both the progressively increasing activity and intensity are an indication that the source may be a significant structural defect which is responding to increases of stress.

The criteria shall be detailed in the AT instruction, Table 9 gives an example. The data shall be evaluated per zone.

For zones that pass the criteria, the class shall be: I non-significant source, no further action.

Any zone that fails one of the criteria shall be further evaluated according to 8.3.5.2.2.

Table 9 — Example for in-service evaluation criteria for steel with yield stress <460 MPa

Maximum allowable hits above evaluation threshold E_T	Maximum allowable high peak amplitude hits E_A	Maximum allowable hits during holds E_H	Maximum allowable activity increase with respect to load E_{AL}	Maximum allowable energy increase with respect to load E_{EL}
5 up to $P_{max\ 12\ month}$ 20 per 5 % further pressure increase	0 >65 dB_{AE}	2 beyond 2 min from start of hold	No increase	No increase
E_T = Peak amplitude of a Hsu-Nielsen source at 10 cm from the sensor centre - 45 dB				

8.3.5.2.2 Second evaluation step based on historic index and severity value

The second part of the evaluation shall be based on the values of the historic index and severity value as defined below.

a) Historic index:

   1) average energy of the last H percent of the AE hits divided by average energy of all AE hits;

   2) the historic index indicates if the intensity is increasing progressively or degressively for that zone.

b) Severity value:

   1) average energy of the S AE hits with the highest energy;

   2) the severity value indicates the intensity for that zone.

The values of H and S shall be specified in the AT instruction, typical values are H=20 and S=10.

An intensity chart shall be defined with the historic index on the X axis and the severity value on the Y axis. The chart area shall be divided in at least 4 classification areas.

The intensity chart shall be defined in detail in the AT instruction, an example is given in Figure 4 with the zone numbers indicated in the chart.

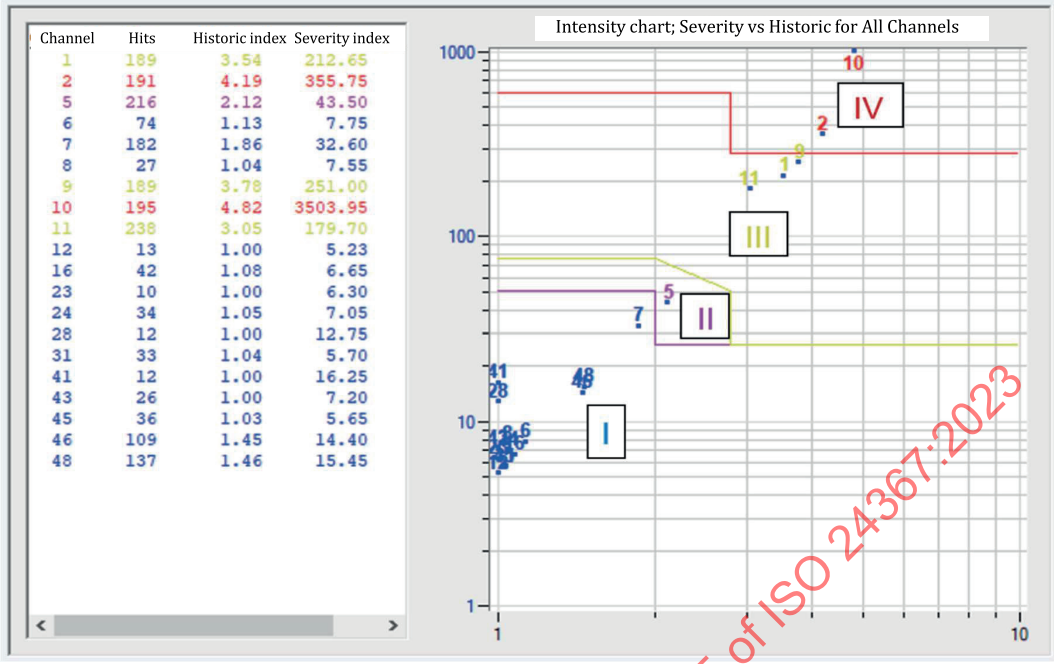


Figure 4 — Example intensity chart with the classes

The classes and connected recommended actions for these zones are specified in the Table 10.

Table 10 — Classification method based on area in intensity chart for zone location of acoustic emission sources

Class	I	II	III	IV
Area in intensity chart	I	II	III	IV

The areas I, II, III and IV in Table 10 shall be specified in the AT instruction by the test organization according to the results obtained from verification tests. The test shall be stopped if the area IV is reached.

For the zones with high classes, planar location using the data at acquisition threshold may assist in finding the actual location of the source so follow-up NDT can be performed efficiently.

9 Acceptance criteria

The acceptance criteria shall be agreed upon by the testing organization and owner/user of the pressure equipment. If the acceptance criteria are not clearly specified, the test report shall state that the test object has failed the test in case an AE source of class IV has been identified.

Follow-up with other suitable NDT methods shall be performed according to Table 1.

10 Documentation

10.1 General

The documentation shall consist of the following:

a) the written AT instruction;

b) the test records;