Development of an acoustic emission signal recording system

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Abstract: *The objective of this study is to develop a system for recording and processing acoustic emission signals. The research focuses on designing cost-effective experimental equipment for investigating acoustic emission processes under laboratory conditions, with the capability of being reconfigured for specific applications depending on loading conditions and methods, material properties, environmental conditions, etc. A laboratory rig for recording and analysing acoustic emission data has been developed and experimentally tested. This paper presents the system's block diagram and its operational algorithm. Furthermore, the correlation between the results of statistical processing of the recorded data and the physical characteristics of the input signals is demonstrated using model acoustic signals, incorporating various components of the developed rig.*

Keywords: *non-destructive testing, acoustic emission method, acoustic emission signal recording, laboratory test rig, acoustic emission source modelling, impulse signal.*

1. Introduction

The acoustic emission (AE) method is highly sensitive and effective for monitoring the early stages of defect development. It enables real-time identification of the damage zone, improving the speed and accuracy of inspection while reducing the scanning volume and monitored area. The key informative parameters that characterise the AE signal include amplitude, energy, signal count, oscillation count, count rate, cumulative count, activity, arrival time, rise time, leading edge slope, first half-wave duration, and others.

Each AE signal parameter is associated with a specific parameter of the destruction process and serves as its acoustic representation. The ability to overlay the loading diagram onto the time dependencies of the main informative AE signal parameters allows for the assessment of their dynamic changes in relation to the load level [2]. In the study of physical properties and material structures, the acoustic emission method of non-destructive testing plays a crucial role. This method is based on measuring the velocity and attenuation coefficient of elastic waves. Its key advantage is that it enables the acquisition of information about the internal structure of materials.

The technology of the AE testing method is based on the acoustic emission effect. Acoustic emission (AE) is the process of a material emitting mechanical waves caused by a local dynamic reconfiguration of its internal structure under external influence. As these waves reach the material's surface, they propagate further in the form of surface waves, inducing mechanical vibrations with amplitudes ranging from 10^{-14} to 10^{-7} m. The detection of such minute vibrations is carried out using piezoelectric sensors.

An important aspect is the analysis of recorded data and the selection of useful information. Despite noise suppression using the frequency method, noise can still make up 99% of the recorded data. This is because the destruction process during the operation of a structure usually occurs slowly, whereas the presence of acoustic noise is an inherent feature of the technological process. Noise reduction after data recording is carried out within the system's software.

Although filtering algorithms may be specific to each application, several general approaches can be identified. Firstly, correlation analysis is applied to examine the relationships between measured AE signal parameters. There are well-established parameter ratios for real AE signals that differ from those of noise signals. The use of parameter correlation is highly effective. The aim of this study is to develop a system for recording and processing acoustic emission signals. The research focuses on designing cost-effective experimental equipment for studying acoustic emission processes under laboratory conditions, with the flexibility to be reconfigured for specific, more specialised tasks, depending on the loading method, material type, and other factors. The primary objective of experimental planning is to achieve maximum measurement accuracy with the minimum number of tests while maintaining the statistical reliability of the results.

Experimental design methods help minimise the number of necessary tests, establish a rational order, and determine the conditions for conducting studies based on their type and the required accuracy of results [1]. To ensure the desired measurement accuracy of input parameters, it is essential to define the range of possible input parameter measurements and refine the types of external influences.

The selection of sample types or test objects should consider their similarity to the actual product in terms of condition, structure, shape, size, and other characteristics for the registration, processing, and analysis of AE signals. Since AE sensors are piezoelectric sensors with high output impedance and a broad frequency range, and given the low amplitude of AE signals during the plastic deformation stage, the primary requirement for the AE signal recording rig is high sensitivity and low intrinsic noise levels.

2. Main stages of developing an acoustic emission system

The development of such equipment involves the following key stages:

- selection of hardware components with sufficient sensitivity, high speed, and low noise levels;
- calibration procedures for the developed device;
- testing using model signals;
- carrying out experimental studies employing the developed rig;
- analysis of informative parameters and identification of new parameters for the analysis of recorded acoustic emission data;
- interpretation of results, both in comparison with known data and within the framework of scientific concepts.

The main requirements for acoustic emission recording equipment are determined by the characteristics of AE signals, which include their complex nature, low energy level, wide frequency range, significant dynamic variations, etc. Therefore, the receiving transducer and the subsequent electronic units must introduce minimal distortion to the signal shape, possess high sensitivity and

a high amplification factor, and maintain a low level of intrinsic noise [2]. Due to the low energy of AE pulses, resonance piezoelectric transducers are commonly used to enhance sensitivity. These transducers have extremely high output impedance, a broad operational frequency range, and a low level of intrinsic noise.
The main components of the developed laboratory system for recording acoustic emissions include:

- AES sensor (Acoustic Emission Sensor)
- broadband low-noise amplifier
- ADC unit (Analog-to-Digital Converter)
- personal computer
- software

During the testing of the acoustic emission equipment, the following conditions were maintained:

- ambient air temperature in the room: 21 °C
- relative air humidity: 70%
- atmospheric pressure: 102 kPa (720 mmHg)
- power supply voltage: 220 V
- power supply frequency: 50 Hz

Before conducting the laboratory tests, all devices were properly grounded.

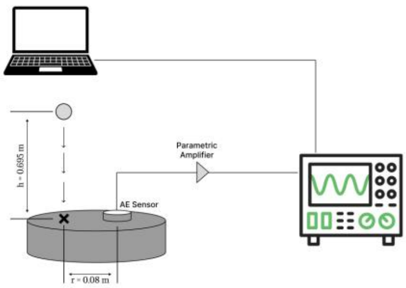

Fig.1 *Laboratory system for acoustic emission recording*

The functionality of the developed rig was tested using various signal sources with parameters that to some extent resemble those of real acoustic emission sources. To validate the method, a series of experiments was conducted using model excitation of different types of AE signal sources. As different types of signal sources, the pencil lead break was used (Hsu-Nielsen source).
The essence of the invention is considered using the example of processing AE signals excited by the specified Hsu-Nielsen type sources and recorded during the propagation of acoustic waves in a steel plate at various distances from the receiver, as well as AE signals generated by the impact of a bearing ball.

3. Modelling of an AE signal source through pencil lead break

This method is recommended for calibrating AE sensors. The acoustic signal generated during the pencil lead break also serves as a model signal [6]. In the experiments, a 0.5 mm diameter pencil lead was used. A 5 mm thick steel plate was employed as the acoustically conductive medium. The AE sensor was mounted 80 mm from the signal source. To ensure optimal contact between the sensor and the plate, a layer of epoxy resin was applied.
A typical signal recorded by the rig during the pencil lead break, along with its spectrum, is shown in the figure below.

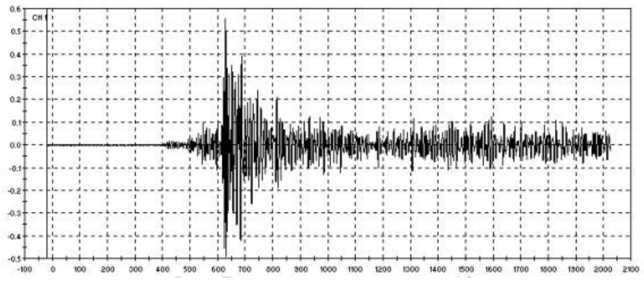

Fig.2 *Typical AE pulse signal*

4. Modelling of an AE signal source by bearing ball impact

The model signal was generated by the impact of a falling steel ball, producing an acoustic wave. Assuming that most of the ball's potential energy is converted by the sensor into an electrical signal, similar to waves generated by real AE sources, it follows that the ball's mass is proportional to the signal energy. The free fall of the ball onto a metallic base was conducted from a height of 695 mm into an area located 80 mm from the mounted AE sensor.
Each ball was dropped at least five times. A piezoelectric transducer was used to record AE signals, functioning as a broadband acoustic emission transducer. The transducer was connected to a preamplifier with a gain of 40 dB, the output of which was linked to the AE recording system with analog-to-digital signal conversion. The positions of the transducer, serving as the AE signal receiver, and the AE sources on the surface of the plate are shown in Figure 1.

The analysis of the obtained data showed that the energy of the signal (elastic wave) generated by the impact of the steel ball on the plate varies linearly with the increase in the ball's mass. Thus, not only was a previously known method of AE sensor calibration applied, but a linear relationship between the energy of the spectrum and the mass of the ball was also demonstrated. This finding enables the future use of this methodology as a rapid calibration method for the device before conducting measurements [3,4].
In addition to the factors already mentioned, the sensor itself has a significant influence on the signal shape. When a broadband emission signal interacts with a resonant sensor, it produces a "bell effect", where the sensor resonates at a specific frequency regardless of the excitation method. As a result, multiple factors simultaneously affect the signal shape at the sensor's output, including paths of wave propagation, the presence of different signals traveling at varying speeds, and the transformation of the input signal by the sensor.

Conclusions

A laboratory rig for recording and analysing acoustic emission data has been developed and experimentally tested. The block diagram of the system and its operational algorithm have been presented. The relationship between the results of statistical processing of the recorded data and the physical characteristics of the input signals is demonstrated using model acoustic signals with various components of the developed rig. The functionality of the laboratory rig was verified through experimental testing.
A model signal was generated by the impact of a falling steel ball, producing an acoustic wave. In the experiments, steel balls of varying masses from rolling bearings were used. Assuming that most of the ball's potential energy is converted by the sensor into an electrical signal, similar to waves generated by real AE sources, it was considered that the mass of the ball would be proportional to the energy of the signal.

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