Nonthreshold Acoustic Emission Data Registration Principles

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Abstract. Traditional way of acoustic emission (AE) signals registration is a threshold method. AE impulse is registered when acoustic signal exceeds preset threshold, and impulse standard parameters (amplitude, arrival time, rise time, duration and others) are counted in on-line mode. Threshold method is simple and stable one, but has a set of drawbacks.

First of all, threshold value is set by operator, thus it could be set incorrectly due to human factor. Secondly, AE - impulse arrival time is calculated as time of threshold crossing, this value differs from real one, what leads to imprecision in AE sources location. Thirdly, threshold method considers acoustic emission as an impulse process with stationary noise background, this model does not suit to continuous emission or non-stationary noise cases.

Intelligent nonthreshold method, based on theory of signal detection, may be considered as alternative to threshold method for AE impulse detection. In this approach AE impulses are detected as fragments of continuous data flow, which has specific waveform and frequency characteristics. Method implementation involves usage of adaptive and matched filtering and change point detecting algorithms in on-line mode.

Intelligent method allows to evaluate impulses arrival times and detect impulses with amplitudes below noise level with help of adaptive filtering. High time accuracy AE - impulses detecting provides precise AE - sources location and criteria estimation, which enhances AE - testing method validity.

By means of digital signal processing impulse and continuous signal products are extracted. AE signal continuous component is analyzed separately. Continuous component analysis allows to identify leaks, technological noise and pre-destruction continuous emission. Currently, due to the high level of circuit technology development nonthreshold algorithm of AE data acquisition can be implemented in hardware.

Introduction

Conveniently AE-systems perform a threshold method of data registration, AE-impulses are detected when a signal exceeds certain threshold value. The threshold method is the most simple one of AE-impulses detection against noise background. In spite of threshold algorithm simplicity and formality, arguably it corresponds to a diagnostic model of a signal. A threshold allows to cut off meaningless signal component and extract informative one – AE-impulses. Threshold registration combines two functions in a one method - signal filtering below threshold and AE-impulses detection by threshold crossing with further AE-impulses parameters estimation.

In spite of mentioned advantages, it is must be said, that an operator carries full charge of testing results validity in the threshold registration. Inappropriately set threshold value leads to faulty interpretation of AE-testing results. Due to human factor vulnerability of AE-testing its level of being in demand is rather low in comparison with other testing methods. Automation of data registration is essential to overcome AE-testing low demand level. Investigations in the field of that task have been being pursued for sufficiently long time. Most modern AE systems, in addition to the conventional threshold processing of AE data, are supplied with an advanced floating threshold method. The floating threshold varies according to a noise level registered by the AE system [1]. Multi-threshold method is applicable either, in this method signal crossing of several thresholds is registered and simple threshold methods drawbacks are compensated by registered information redundancy. Another way of AE-testing validity enhancing is continuous data registration. Human factor is excepted here by full recording of diagnostic information without threshold limitations. Noise filtering, AE-impulses detection and its parameters estimation are done by expert system software in off-line mode.

Current paper considers possible design of AE – system, that uses threshold-free method of data registration. In this method of data acquisition signal filtering and AE-impulses detection is done by intelligent signal processing methods that work automatically without involving of operator. It is expected that such system design could be a comprehensive solution of AE-testing results subjectivity and invalidity overcoming task. Article presents analysis of different signal processing methods application in current task.

1. Intelligent AE signal filtering

In industrial AE-systems implemented filters, as usual, are frequency band ones and hardware ones for pulse electromagnetic noise rejection. In this regard primary way of noise rejection is threshold limitation of AE-signals. If threshold method is abandoned, alternative way of noise filtering should be developed.

Main problem of AE-data filtering is versatility of informative signals waveforms and noise parameters. AE-impulses could vary by their amplitudes for thousand times and by their duration for hundred times, their spectral properties are highly determined by acoustic channel qualities. Noise properties could vary in vast limits depending on conditions of testing performing. Noise could be white or colored, correlated or not, its amplitude level varies greatly. Besides frequency bands of AE-impulses and noise usually intersects. Taking the above into account, effective AE-data filtering is possible only with assumptions about AE-impulses waveforms and noise parameters. Filtering algorithm complexity depends on degree of apriori uncertainty of current task.

1.1 Stationary noise filtering

Practical widespread case is noise sources that generate during AE-testing noise signal with known and permanent stationary parameters. In that case it is possible to record a pattern noise signal. Wiener optimum filter could be used for filtering of stationary correlated noise[11]. Fig.1a presents signal, where AE-impulse is exposed against friction noise, Fig.1b presents filtering results. After filtering signal-to-noise ratio has increased in ten times.

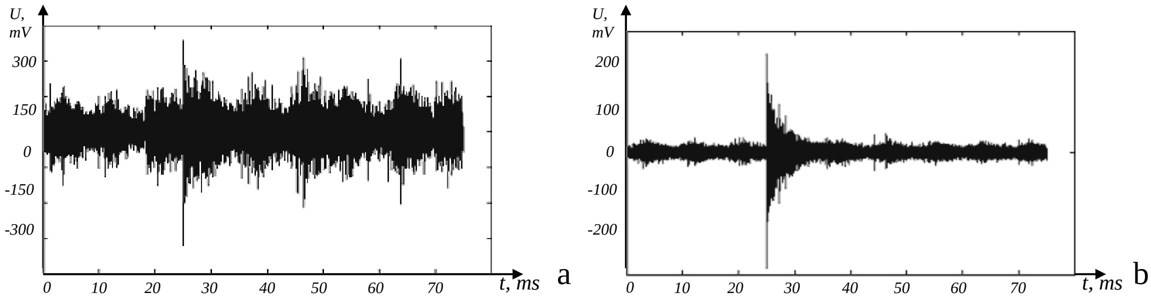


Fig.1 a. AE impulse against the rubbing noise background SNR<0.9 b. Result of the Wiener filter application SNR>10.

For stationary white noise filtering wavelet thresholding application is effective [10]. This application result is shown on Fig.2. Fig.2a presents initial long-waveform AE signal, where AE-impulses are exposed against stationary white noise, Fig.2b presents filtering result, noise level was reduced for more than one order.

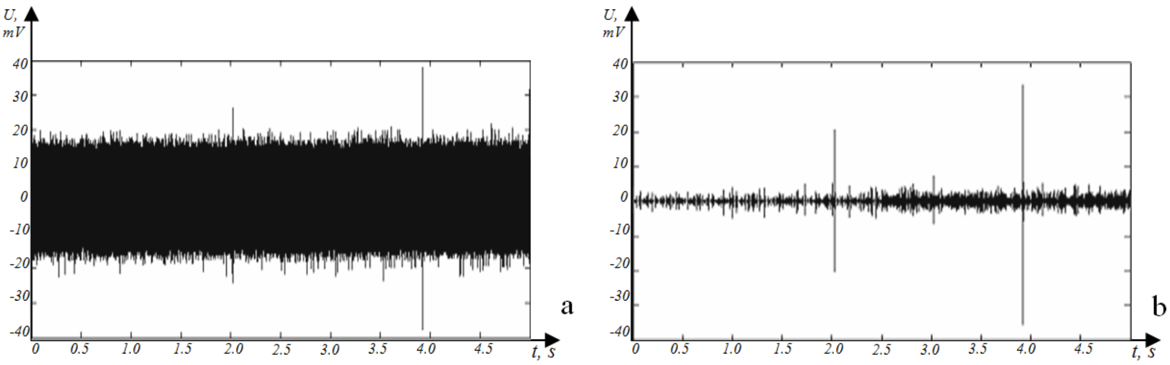


Fig. 2 Wavelet-filtering of AE signal long realization a) initial signal; b) filtering result

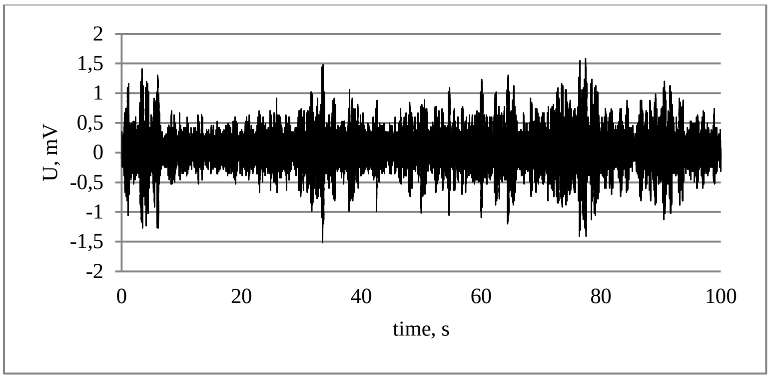
1.2 AE-data filtering in case of apriori uncertainty

During AE-testing noise influence is not always clearly predictable. Complex acoustic environment, rainfall influence, technological facility work modes switching – all influence on acoustic signals noise background parameters. Therefore in the most general case apriori uncertainty of noise process parameters should be postulated. Even in case of apriori uncertainty it is possible to apply stable and reliable way of filtering – it is bank of matched filters, based on impulse nature of informative AE-signals. Matched filters operation concept could be demonstrated on example.

Long-waveform AE signal, that is a fragment of non-stationary noise with duration of 100 ms is shown on Fig.3a, noise masks AE-impulse. Signal-to-noise ratio for signal under consideration is less than 0.7, therefore AE-impulse is not seen against noise background. Fig.3b presents continuous wavelet transform of current signal. On the time-scale plane AE-impulse is detected in located range of scale factor, and in this range AE-impulse energy exceeds noise energy.

Continuous wavelet transform could be considered as a set of matched filters. Each scalogram string is an initial signal that is processed by filter with impulse response as wavelet-function form with certain relevant value of scale factor. If form of wavelet-function in some approximation corresponds to AE-impulse form, then transform, shown on Fig.3b, could be interpreted as a result of matched filters set processing. [13]

Analysed AE-signal and wavelet-function are matched by duration. As best extraction of AE-impulse from noise background occurs when its form and duration coincides with filter impulse response, AE-impulses with different duration would be extracted with different values of scale factor. The more long-time AE-impulse is, the bigger value of scale factor for matched filter should be.



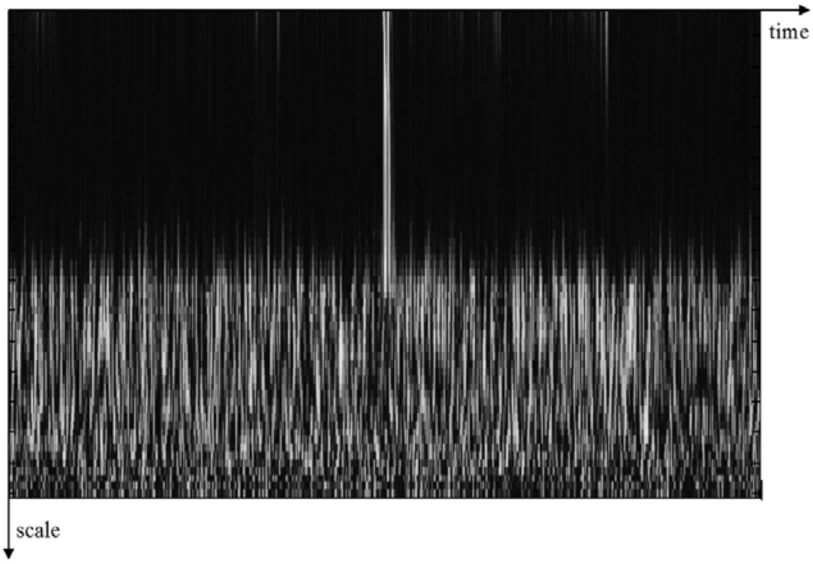


Fig. 3 Noised signal and it's continuous wavelet transform

Continuous wavelet transform counting demands mighty computational effort and could not be implemented in on-line mode. For matched filtering implementation it's sufficient to choose optimal set of scale factor values, which would provide detection of AE-impulses with different durations. In current work informative range of scale factor was set by minimization of objective function that provides best extraction of AE-impulses with minimal and maximal durations from noise. Number of wavelet-filters was minimized either.

Fig.4 and 5 presents results of filtration. Fig. 4a shows a signal in which the AE impulses observed on the background of the high noise level. Signal to noise ratio is less than one. Fig.4b shows filtration result, the impulses with the amplitudes less the noise level was detected. Fig. 5a shows the AE signal produced in the laboratory conditions. AE impulses were emitted with help of calibrator at regular intervals. Vibration noise was present only during the half of the recording time. As a result of filtering (fig. 5b) noise was completely deleted.

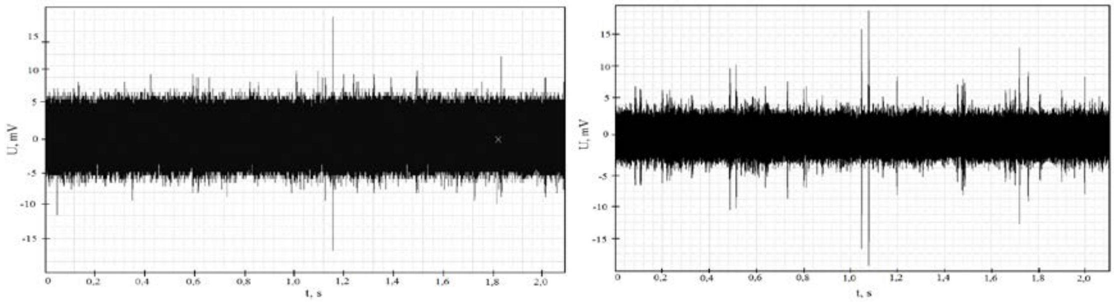


Fig.4 AE signal with high noise level and its filtering result

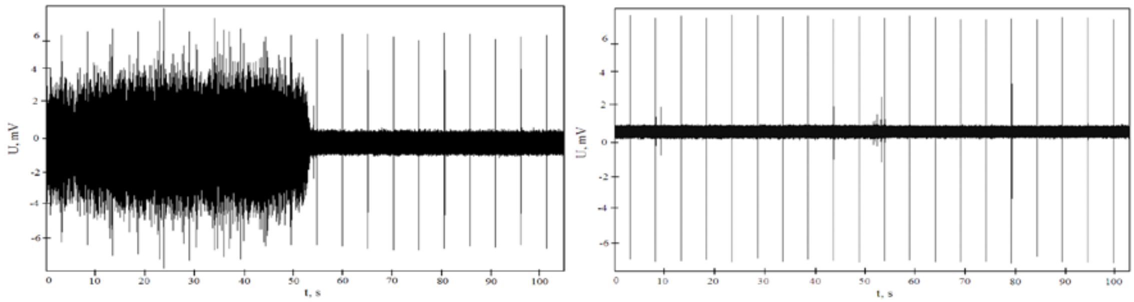


Fig. 5 AE signal against vibration noise and its filtering result

2. Threshold-free AE-impulses detection

In the context of AE-impulses against noise detection task signal could be observed as a stochastic noise process with burst temporary change points. Change points are AE-impulses that create short-time change of noise process properties. Therefore task of AE-impulses in data flow detection could be formulated as task of change points detection in temporary series.

There is a variety of change point detection methods, that are successfully applicable for AE-signals analysis – maximum likelihood ratio [5], Akaike information criteria [3], method of higher order moments [4,6], method of intersection of confidential intervals [7-9]. All methods mentioned above were investigated in details in work [12], with their application specifics and accuracy of AE-impulses detection against differently leveled noises.

Series application of different detection algorithms should be performed for higher validity of detection, where light computational effort methods are desirable to be applied first as rude extracting of time interval with AE-impulse, and then accurate definition of AE-impulse start time within found interval by means of more complex methods is performed.

2.1 Threshold-free data registration general scheme

Fig.7 illustrates general scheme of threshold-free data registration for long-waveform AE signal. Algorithm is based on the method LTA/STA [2], long time window serves for continuous component of signal analysis. Statistical average signals parameters are analyzed to identify dangerous conditions of tested object, such as leak or continuous emission right before destruction.

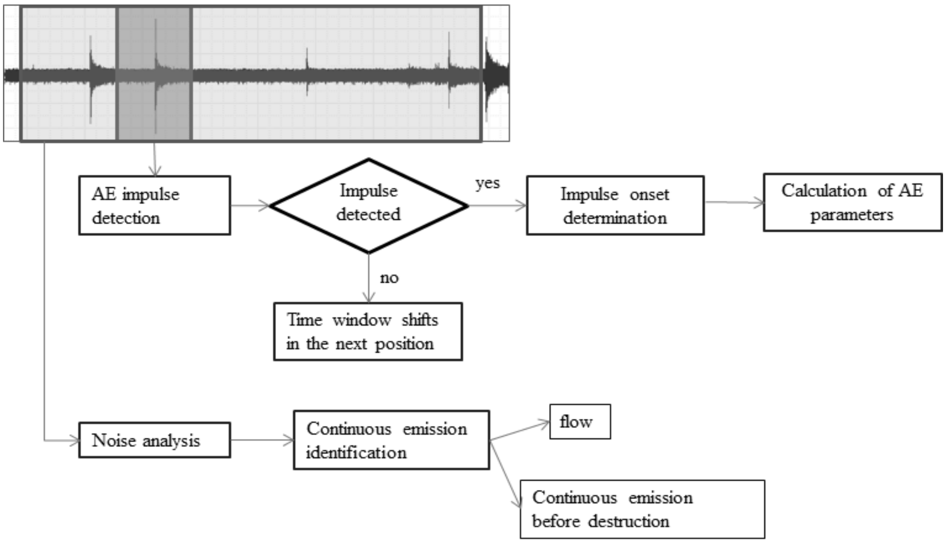


Fig.6 Threshold-free data registration scheme

2.2 Signal detection methods application to AE-data specific

Change point detection methods do not need threshold values setting, but time window size should be specified to define scale of signal observation. Impulse detection validity and start time counting accuracy depend on choice of signal observation scale.

There is no one only accurate size of time window. Observation scale is defined almost by frequency band of AE transducer. Low frequency signals demand larger intervals of observation then high frequency ones. Fig.7 presents waveform of AE signals, that were measured by sensors in frequency bands 30-500 kHz and 3-60 kHz, sampling rate in both cases was 2 MHz.

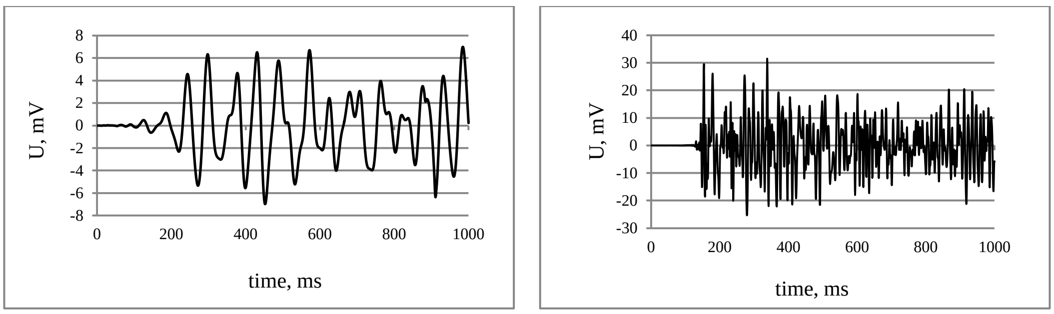


Fig.7 Low-frequency and high-frequency AE signals

The signals have different spectral patterns, and, therefore, different time scale. Rise time of signal on Fig.7a is 35 us, and rise time of signal on Fig.7b is about ten times longer. Duration of analyzed signal fragment should be matched with signal spectral properties for effective AE-impulses detection. As AE-testing could be maintained with different sensors in wide frequency range, task of time window size adaptive choice arises.

This task could be avoided by matching of sample rate with frequency properties of instrumental and acoustic channels of the system. Measuring channel transient function is obtained by means of pulse calibration reaction, and then sample rate and digital filter band are set so, that whatever properties tested object and transducer have, spectrum of discrete signal lies in one and the same discrete frequency range. Fig.8 presents results of calibration procedure. Signals from Fig.7 are sampled with different sample rates. Low frequency signal sample rate is lowered to 250 kHz, so discrete signals spectra occurred in one range.

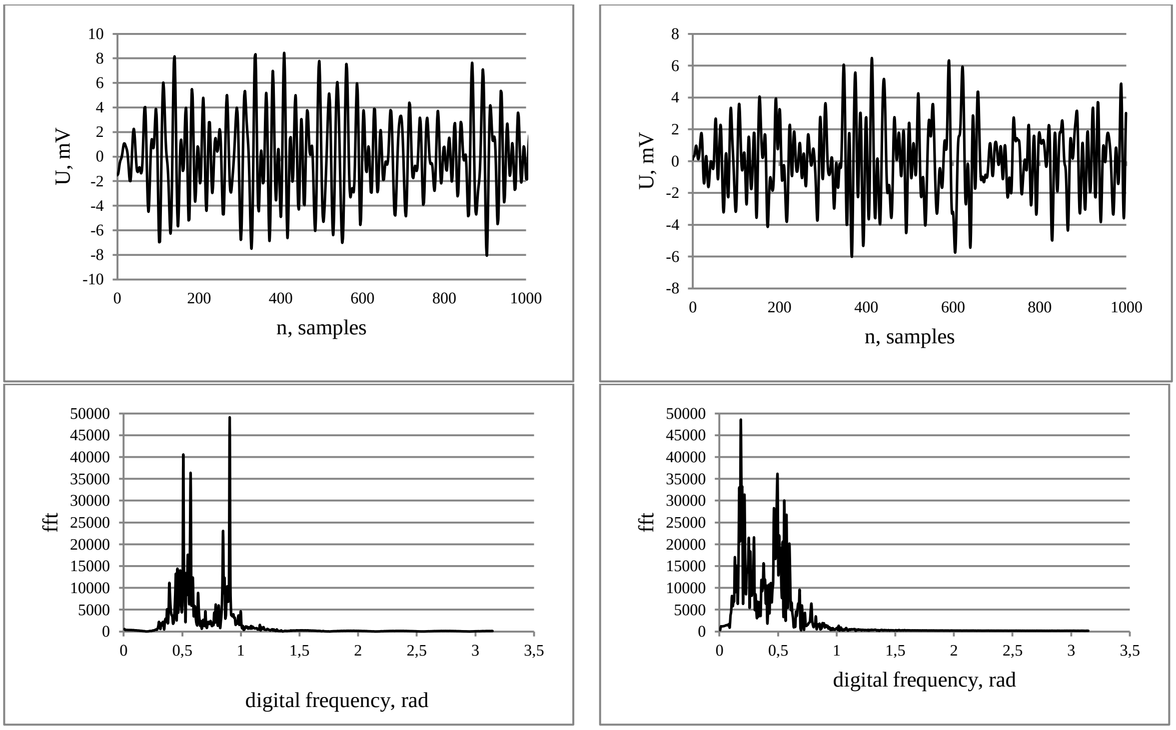


Fig.8 Resampled AE signals and they spectrums

3. Conclusion

The paper considers general principles of non-threshold registration of AE data. The non-threshold acquisition algorithm concludes the following stages - intelligent advanced filtering, AE impulse detection and continuous emission recognition. The general scheme of non-threshold data acquisition was discussed in the paper. The results presented in the paper demonstrate the possibility of design of non-threshold AE data acquisition system

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