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ADVANCED ACOUSTIC EMISSION SIGNAL TREATMENT IN THE AREA OF MECHANICAL CYCLIC LOADING

P. Mazal[1], L. Pazdera[2], L. Kolar[1]

[1]Brno University of Technology, Faculty of Mechanical Engineering, Technicka 2,
CZ 61669 Brno, Czech Rep., *E-mail:* mazal@fme.vutbr.cz

[2] Brno University of Technology, Faculty of Civil Engineering, Zizkova 17,
CZ 60200 Brno, Czech Rep., *E-mail:* pazdera.l@fce.vutbr.cz

ABSTRACT

One of promising possibilities of watching of damage course of material exposed to cyclic mechanical loading is using acoustic emission technique (AE). In the signal monitored on the surface of material, it is possible to identify course of a number of processes that appear both on the surface and inside the material of the construction. From this point of view, we can see that this method could provide us with information about the course of fatigue damage and it could help us specify residual fatigue life. Various types of AE records processing that are often used in practice are dealt with. Results gained to date show wide possibilities of application of the method of acoustic emission for the identification of fatigue processes. In this paper, the basic comments of results of experimental measuring are shown that were aimed to possibilities of identification of various stages of fatigue process, realised on electro-resonance loading equipment with the help of acoustic emission technique.

Keywords*:* Acoustic emission, Fatigue properties, Signal treatment, Burst signal characteristics

1. Introduction

Parts of machines, vehicles and many other constructions are exposed to repeated loading, called cyclic loading. The resulting cyclic stress may cause microscopic damage of the material. In case that the stress is lower than the tensile strength of the material, the damage accumulates by ongoing loading until the damage occurs; it can later cause fracture of the part. This process of accumulation leading to fracture as a result of cyclic loading is called fatigue. Fatigue damage is very dangerous due to the fact that the degradation of properties is gradual and often cannot be seen. Finally it results in a breakdown of a construction. Fatigue process is controlled by cyclic plastic deformation and can be divided into several markedly different stages. Usually, the stage of change of properties, stage of nucleation of microcracks and the inception and growth of short cracks, the inception and spreading of magistral crack and final fracture are distinguished.
Fatigue properties of materials are measured by means of a number of tests and testing equipment based on a variety of principles. The resonance machines, based on the electromagnetic principle are an important group of the diagnostic equipment. These machines are very demanding both on energy and space and they work with frequencies of loading up to

300 Hz. The disadvantage of these machines is considerably restricted volume of information concerning the course of fatigue damage that can be obtained in the course of the experiment.
Taking into account the principle of the tests, the resonance frequency of the system changes and, of course, the energy necessary for having the flexural moment constant as a result of the change of toughness of the sample in the course of fatigue damage changes as well. By means of monitoring of parameters in question (especially frequency), it is possible to estimate the inception of the magistral crack spreading (Fig.1).

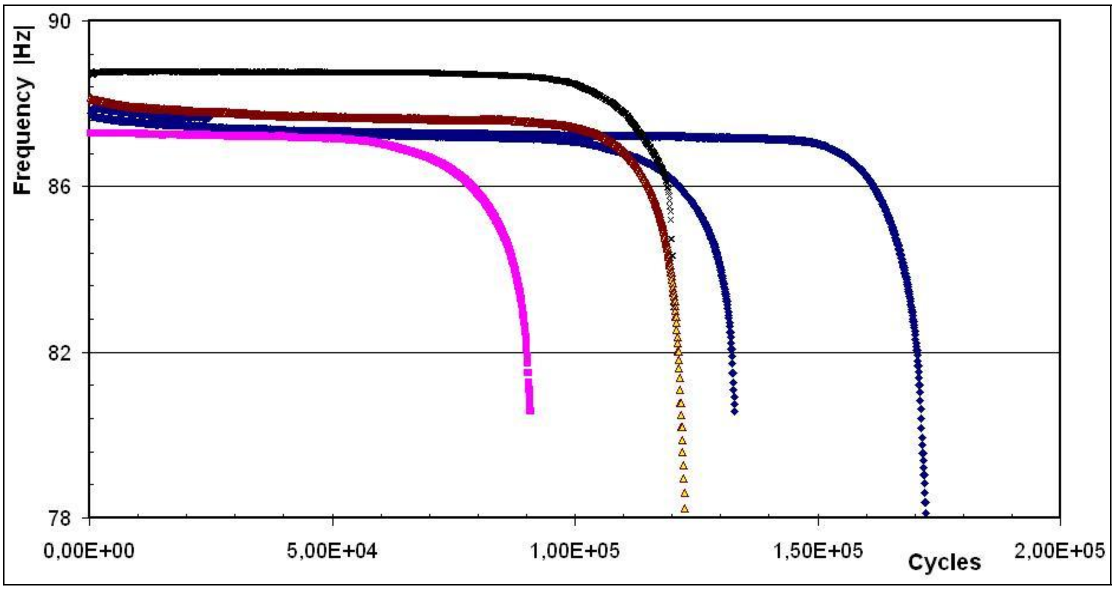

Fig. 1: Exemples of frequency curves of differents materials (steel, grey cast iron, AlMg alloy).

For qualified evaluation of material properties, it is necessary to identify individual stages more precisely. Taking into account the arrangement of experiments and the shapes of the samples, the application of ultrasonic, possibly RTG procedures does not seem very likely. Some possibilities are offered by the utilization of the method of potentiometric methods and the application of the acoustic emission method in this field seems to be very promising.

2. Acoustic emission method

One of intersting possibilities of watching of damage course of material exposed to cyclic mechanical loading is using acoustic emission technique (AE). This modern NDT method is based on knowledge that all active damage in material is a source of oscillation, which spreads in material of loaded construction in all directions. It would be very useful to make fatigue life estimations withouth necessity of setting back the constructions, as it is already done in branch of inspection of pipes, pressure vessels and reservoirs (in these cases the Acoustic Emission method is used routinely).
Reliable use of AE method depends on fulfiling of plenty of conditions. Decisive is of course the influence of measuring devices – transducer, pre-amplifier, and AE analyser. Further the quality of contact between the transducer and material surface, the displacement of transducers, size of tested construction, significant influance has also the possibilities of analysing software etc.
For application of AE method for identification of damage state in practice, it is necessary to accomplish very large-scale experiments in laboratories first, to find out suitable characteristics of AE signal, which could correspond to changes in material.

3. Experimental equipment

We have been using two electro-resonance pulsators RUMUL Cracktronic in the laboratories of fatigue properties of the Institute of Machine Design (Fig. 2). Two differents analyzers Dakel Xedo (4 channels and 2 channels) with 16 level analyses, equipped with sensing software DaeMon and evaluating software DaeShow have been being used for more detailed identification of the course of fatigue damage. The utilization of micro and midi sensors enables them to be fastened into the nearest proximity of the supposed place of damage inception (Fig. 3). Active piezoceramic sensing units with individual pre-amplifier have been connected to measuring channel units of the analyser. Further signal processing was fully done by PC with suitable software installed on it.

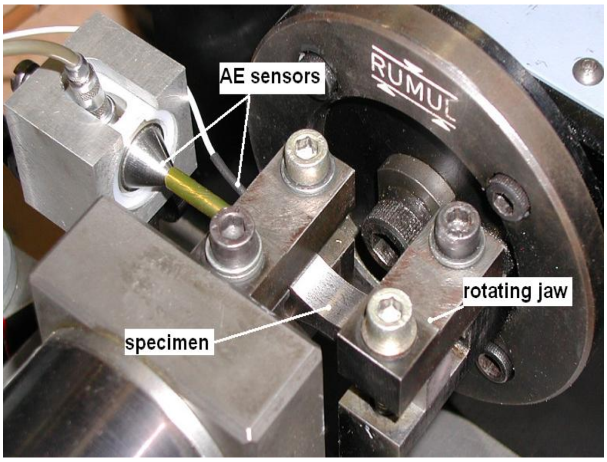

Fig. 2: Arrangement of fatigue tests on electro-resonance testing machine Cracktronic 70.

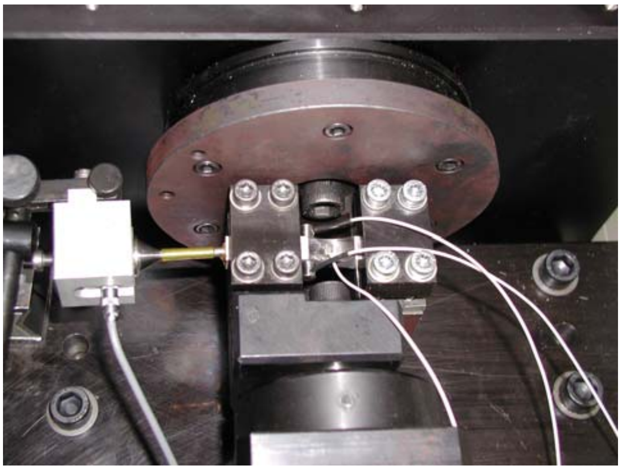

Fig. 3: Testing machine Cracktronic 160 with specimen and 4 pcs of AE sensors.

Currently there exists relatively wide file of records of AE signal frequency and summary curves of AE events and this is why we are aimed to possibilities of events categorisation and changes of their frequency characteristics in the course of degradation of qualities of cyclic loaded material. The most typical types of records that were reached during measuring can be seen in following figures.

4. Experimental results

AE method may be considered to be a basic identification method – the evaluation of the frequency of overshoots, summation curves or RMS value. The changes of AE activities in the course of loading are clearly seen in these records. Changes in the initial period can be seen, when the cyclic hardening or softening of loaded material appears. The growth of activities in the time of supposed inception of magistral crack can be seen too. Often occurring, quite strong and time-restricted growth of AE activities approximately in the middle of the life-time period of the sample is quite surprising and has not been explained positively yet. Individual areas can be showed using, so called level analyses (see Fig. 4, 5 and 6). In this case, various energetic levels of sensed AE events are supposed due to various types of changes that are the resource of the signal (Fig. 4b).
These relatively simple signal processing procedures have been applied to a number of materials – steels, cast iron (often with heat surface treatment), AlMg alloy etc.

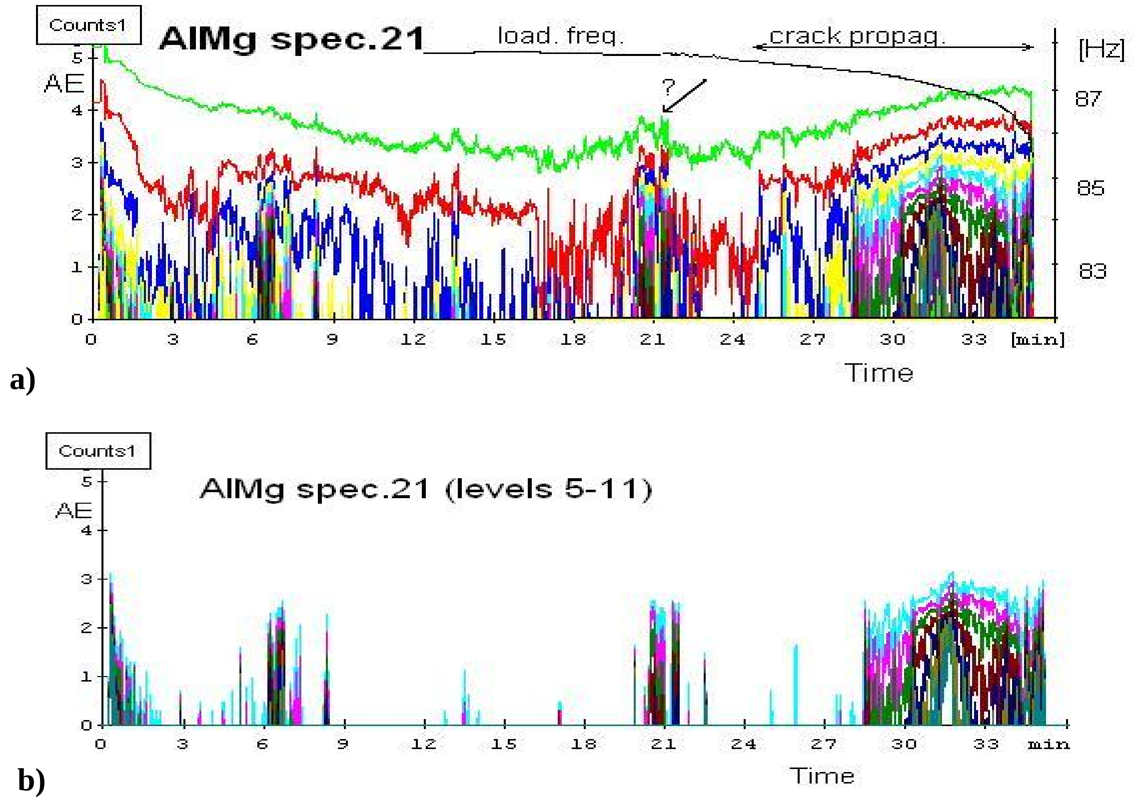

Fig. 4: Exemple of AE burst rate measured in AlMg alloy (final fatigue fracture after app. 1,8.10^{5} load. cycles)   a) all levels, b) only selected levels (No.5-11).

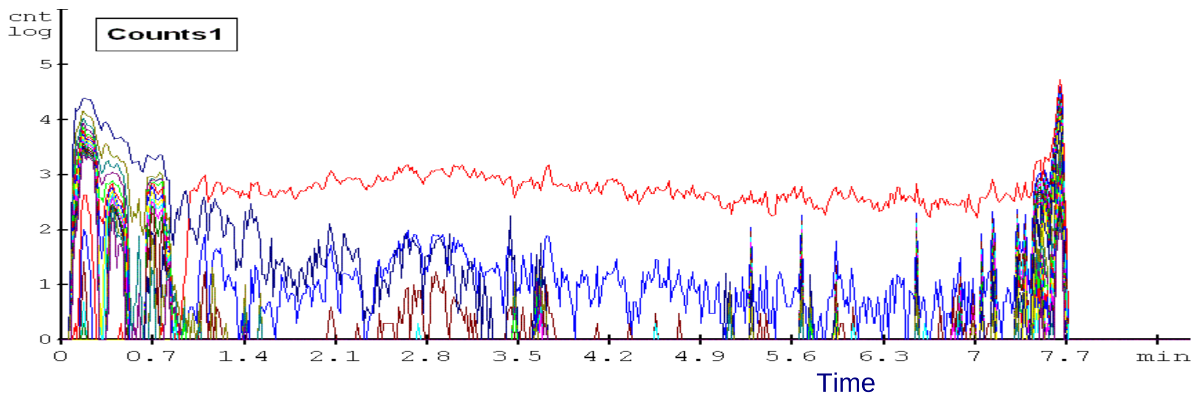

Fig. 5: Exemple of AE burst rate in different measured levels of signal – nodular cast iron (final fatigue fracture after app. 5,0.10 ^{4} load. cycles).

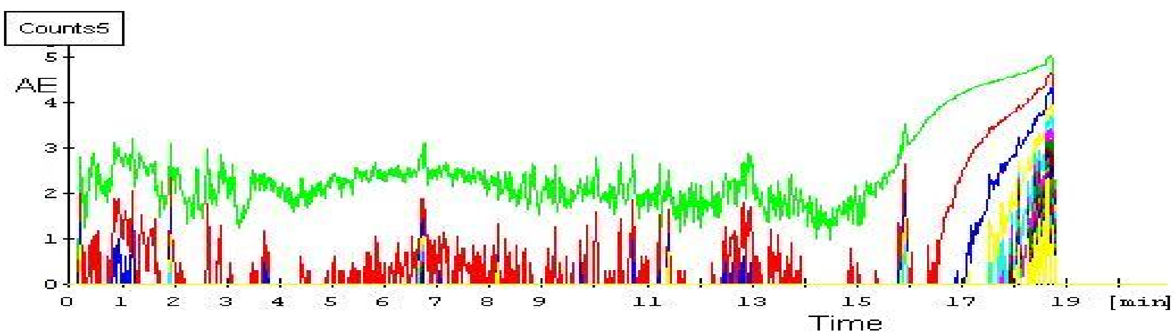

Fig. 6: AE burst rate in different measured levels of signal – steel (fatigue fracture after app. 1,0.10 ^{5} load. cycles).

For the identification of the resource of the signal, it is necessary to use so called advanced AE signal processing that lies in more detailed analysis of some parameters of sensed AE events and in monitoring and statistic evaluation of their changes. Chosen typical records can be seen in figures No.7 - 13.

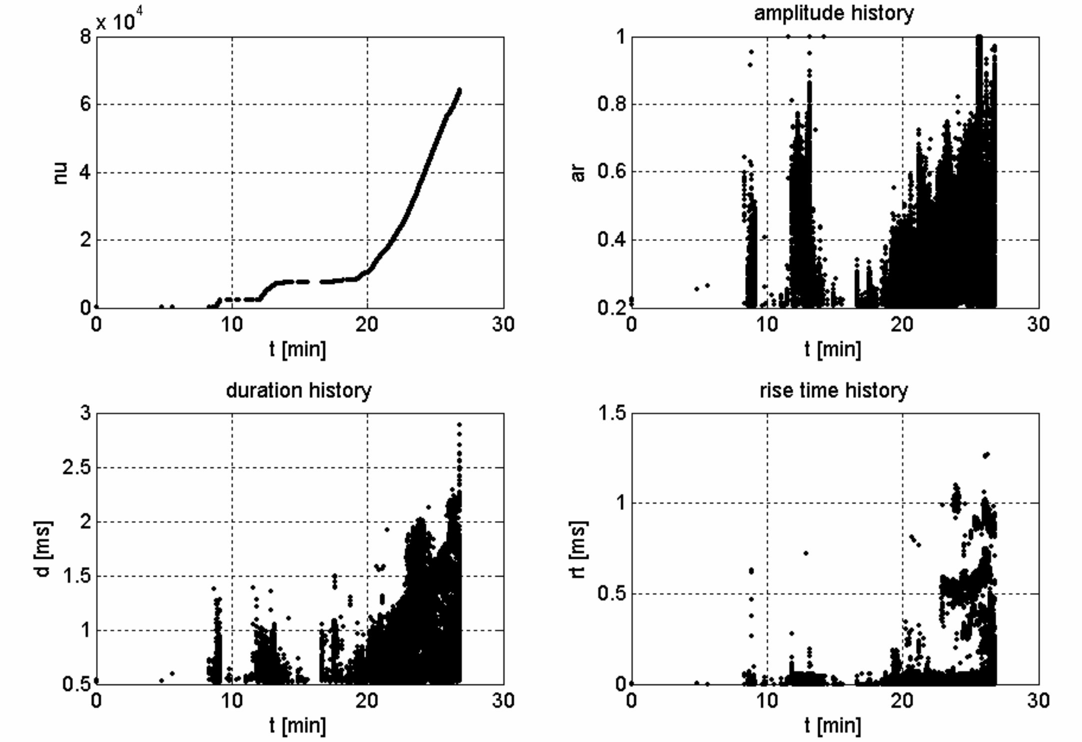

Fig. 7: Overview of AE events parameters treatment – cumulative number, amplitude, duration and rise time history for AlMg aloy.

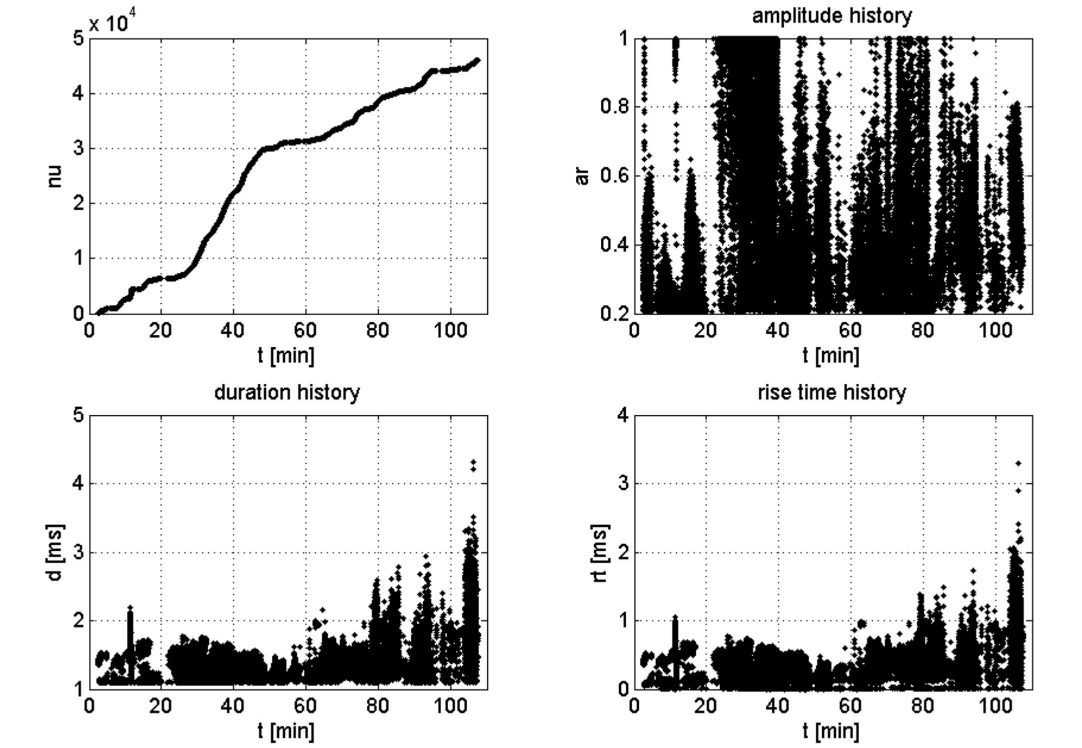

Fig. 8: Exemple of AE events parameters treatment – cumulative number, amplitude, duration and rise time history for low alloy steel.

Examples of other selected characteristics are mentioned in the next part of this chapter. The samples from AlMg alloy and low alloy steel was chosen for evaluation purpose. The event analysis (i.e. analysis of acoustic emission conventional parameters) of low alloy steel was made up from a slot Nr.3. Short Time Fourier Transformation files were chosen from a slot Nr. 2.

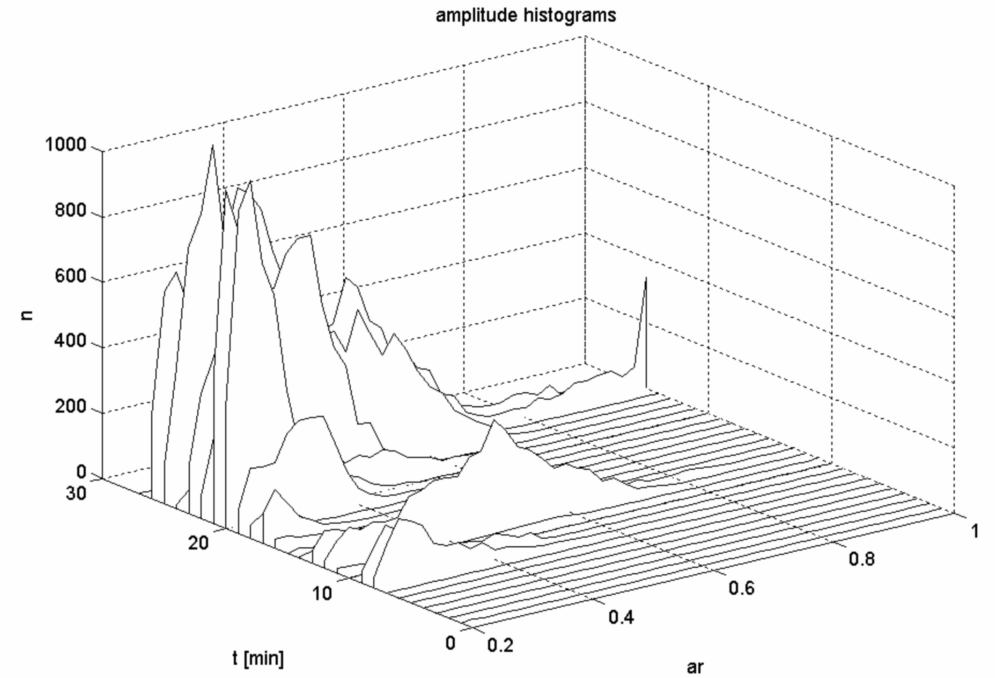

Fig. 9: Exemple of statistical distribution of amplitude, evaluated in 1minute intervals for observed AlMg alloy.

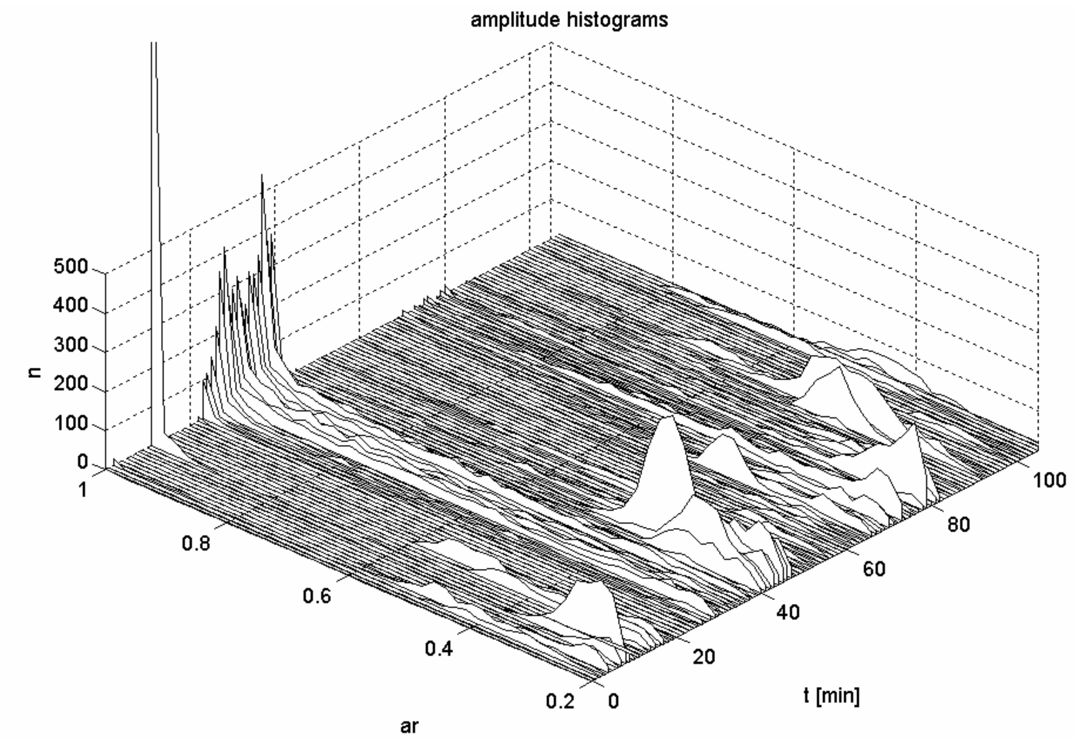

Fig. 10: Exemple of statistical distribution of amplitude, evaluated in 1minute intervals for cyclically loaded low alloy steel.

The other charts in Figs. 9 and 10 show statistical distribution of amplitude, evaluated in 1 minute intervals from the beginning of its measurement. The „mounts” of low amplitudes (in Fig. 10) at about 30% of its maximum are remarkable. Entirely events of the amplitude exceeding the effective range value (100%) are in the area between 30 to 40 minutes. These “peaks” can indicate the origin or propagation of material failures.

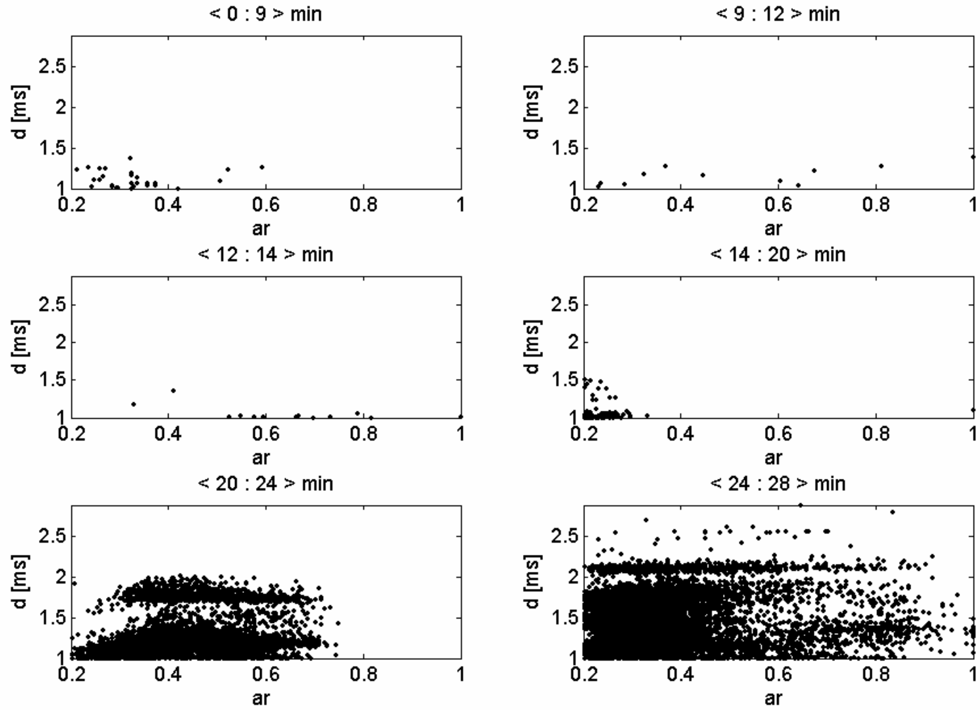

Fig. 11: Selected correlation of AE amplitude graphs in differents time periods (AlMg alloy).

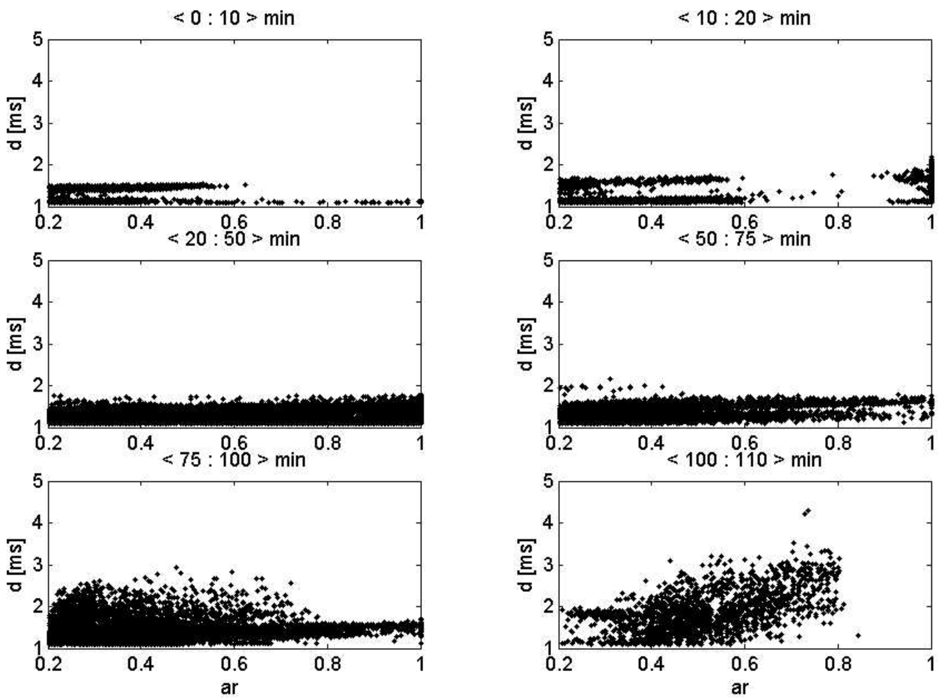

Fig. 12: Correlation AE amplitude graphs in differents time periods for low alloy steel.

The exemples of AE amplitude correlation graphs (Figs. 11 and 12) are divided into six time periods. For exemple in Fig 12 in time up to 10 minutes (or 20 minutes) there are probably two sources of acoustic emission, because their courses are close to „straight lines“. AE events even with large amplitudes are relatively short-termed. In time above 75 minutes the length is increased even when the amplitude decreases.

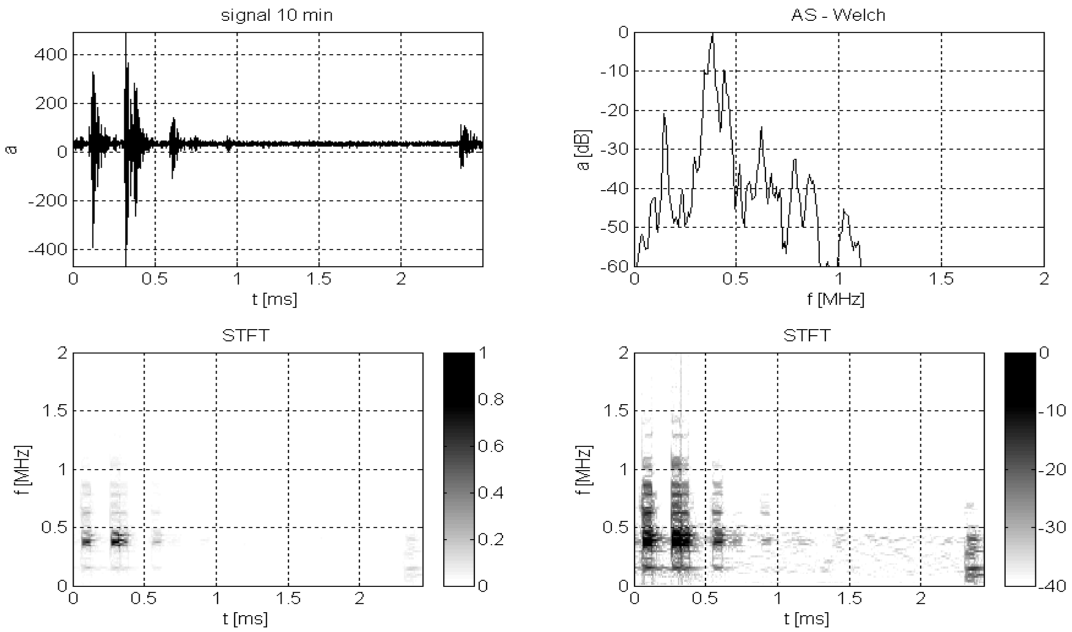

Fig. 13: Exemple of AE events with frequency spectrum and Short Time Fourier Transformation –low alloy steel (loading time 10 min.).

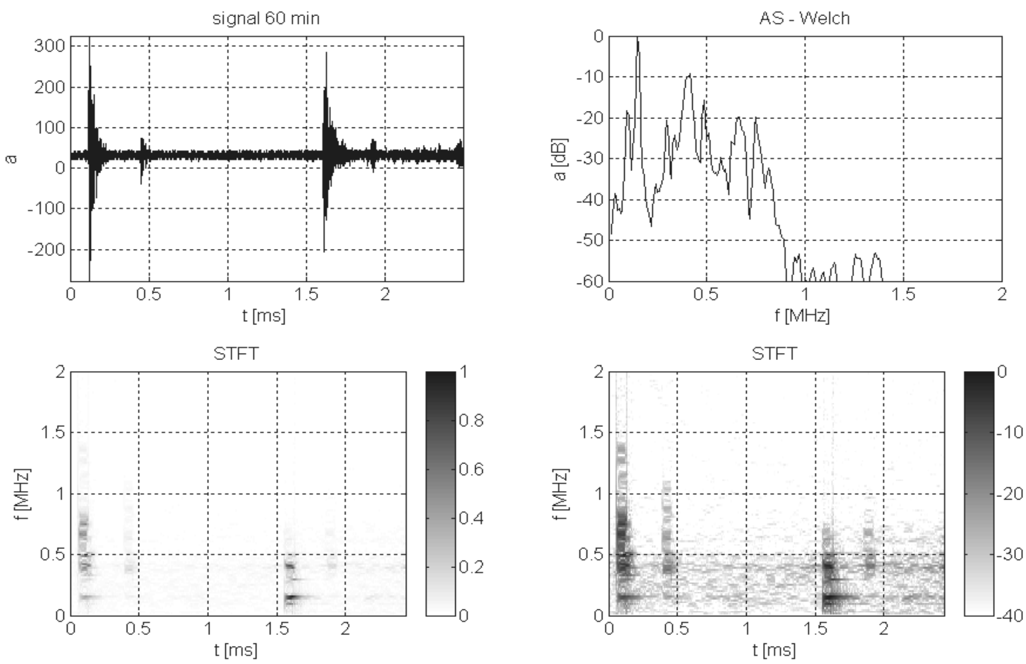

Fig. 14: Exemple of AE events with frequency spectrum and Short Time Fourier Transformation – low alloy steel (loading time 60 min.).

The important source of information about fatigue process in progress is the shape of AE event itself. In this case it is necessary to use evaluating apparatus of higher category. Our current knowledge shows that it is possible to watch very important differences in the shape of events. Figs. 13 and 14 shows charts, displaying realizations and features of recorded AE signals in time of 10 and 60 minutes from the beginning of their measurement. Noted, that these signal was recorded on a slot Nr.2. The left top chart shows an amplitude time course of AE, the right top chart shows frequency spectrum calculated by the Welch method, the bottom charts show an application of Short Time Fourier Transformation both in relative linear display (see left bottom) and logarithmic display (see right bottom).

5. Conclusions

AE method application proved a possibility of the basic identification of individual stages of fatigue processes on electro-resonance pulsators. The technology of acoustic emission enables monitoring of the state in the whole loaded volume of the material and it could enable monitoring of cracks that spread under the surface.
The fact that every measuring is unique is still a great problem for repeatable application of AE method. This is caused by very difficult ensuring absolutely identical conditions of every measuring (often long-lasting). Before all, various materials differ significantly in their "acoustic activity" and its character. The possibility of mutual comparison of results strongly depends on used sensors, on the way they are fastened to the sample, on the contact medium between the surface of the material and the sensor etc. The shape of the samples and the distance between the sensor and the place of monitored defect play an important role, too.
Beyond these restrictive factors, the method of acoustic emission has its indisputable justification for the identification of fatigue degradation stage. It is necessary to work out standard procedures, including rules for setting parameters of AE analyzer, location of sensors, and, of course, the way of evaluation of acquired signal. Extensive experimental work is necessary to work out general procedures of evaluation. Searching for congenial parameters and their fitting into the evaluation programmes will require considerable effort. For qualified estimate of real sources of acoustic emission in material it is necessary to make use of much more demanding signal processing, using suitable mathematics methods. It is necessary to take off characteristic shapes of events in individual stages of damage and to provide detailed frequency analysis.
If we find more sophisticated procedures and a way to eliminate undesirable influences, it will be possible to evaluate the intensity of initial softening or hardening of material. It might lead to more precise identification of the stage of initiation of microcracks and the inception of spreading of short cracks and it can importantly improve the quality of material resistance tests.

Acknowledgement
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6. References

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