Application of advanced AE signal treatment in the area of mechanical cyclic loading

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Abstract: 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. Various types of AE records processing that are often used in practice are dealt with.

1. Introduction

Most of technical constructions are in time of its practical exploatation exposed to cyclic loading (mostly mechanical). During the loading the damage cummulates gradualy, which can cause in some cases loss of properties of the construction and breakdown. These breakdowns can cause not only serious material losses, but also can often endanger human lifes. Very dangerous aspect is, that the cumulation of damage is done withouth any remarkable visible signs.

That is why it is natural that plenty of research teams in whole world are trying to discover new approaches and methods, which could make the estimation of actual status of constructions and eventualy also of its remaining lifetime more accurate. One of promising 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).

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. 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 neccessary to accomplish very large-scale experiments in laboratories first, to find out suitable characteristics of AE signal, which could correspond to changes in material.

Several papers have been published [1, 2] in the area of searching for suitable parameters of events that would describe changes of fatigue properties. E.g. a number of experimental results directly from the area of fatigue loading can be found in [3, 4, 5, 6]. The attention is focused on frequency characteristics of individual events and their changes (Fouriere transformation or Wavelet transformation are used). Peak amplitude, rise time, duration of signal, RMS etc. are among other monitored parameters. Current results show that together with changes of damage, the importance of mentioned parameters changes as well, e.g. in the stage of stable spreading of crack, the amplitude of signal is the most important parameter, while in case of instable spreading of crack, the importance of rise time grows and the importance of the time of the event drops, etc. [7].

2. Experimental equipment

Tests of classical fatigue presented in this paper were realised on two different electro-resonant testing systems RUMUL Cracktronic. These machines work in conditions of flat four-points bending. Frequency of loading is in range of 80 to 150 Hz. Typical arrangement of the fatigue test is shown on Fig. 1.

AE laboratory in Institute of Mechanical Design currently uses 5 different types of AE analysers - from relatively simple AE 10C (only with basic functions) to the two channels analyser Dakel Xedo and newly four channel system Dakel Xedo with 16 level analyses. Active piezo-ceramic sensing units either with individual or integrated pre-amplifier have been connected to measuring channel units of this equipment for acoustic emission measuring. Further signal processing is fully done by PC with suitable software installed on it.

The laboratory is newly equipped with the new software DaeShow ©. This software makes possible the detailed analysis of the AE signal. Beside the "classical" information about AE activity we have the possibility to create "catalogue" of event parameters in differents stages of the fatigue process on different types of materials. It is possible to use different parameters e.g. peak amplitude, rise time, signal duration etc. for all AE events and search for parameters typical for different stages of the fatigue life of materials and constructions.

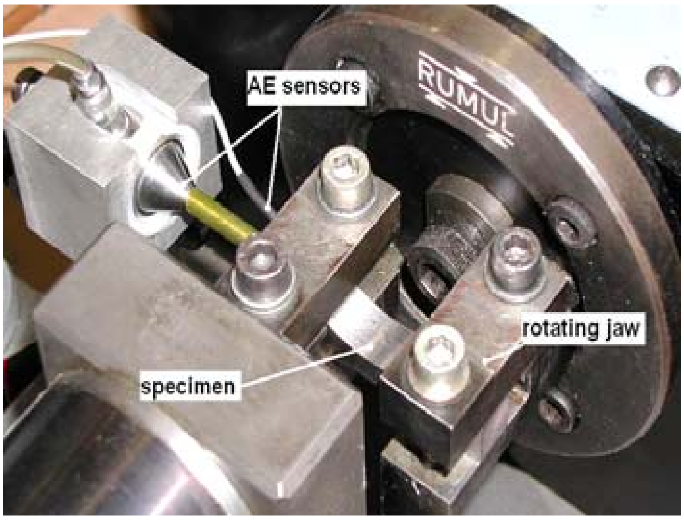

Fig.1 Arrangement of AE tests on electro-resonance testing machine

3. Experimental results

In recent time in laboratories of Institute of Design we are occupied by identification of AE signal characteristics during cyclic loading of carbon steels, low alloy steels, grey cast irons and nodular cast iron.

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.

The first group represents the records of changes of total AE frequency of events - acoustic emission ring down counts rate (usually in different energetic levels). In these type of graphs (Fig 2) initial stadium of changes of fatigue properties can be identified as well as the stadium of magistral fatigue crack spreading.

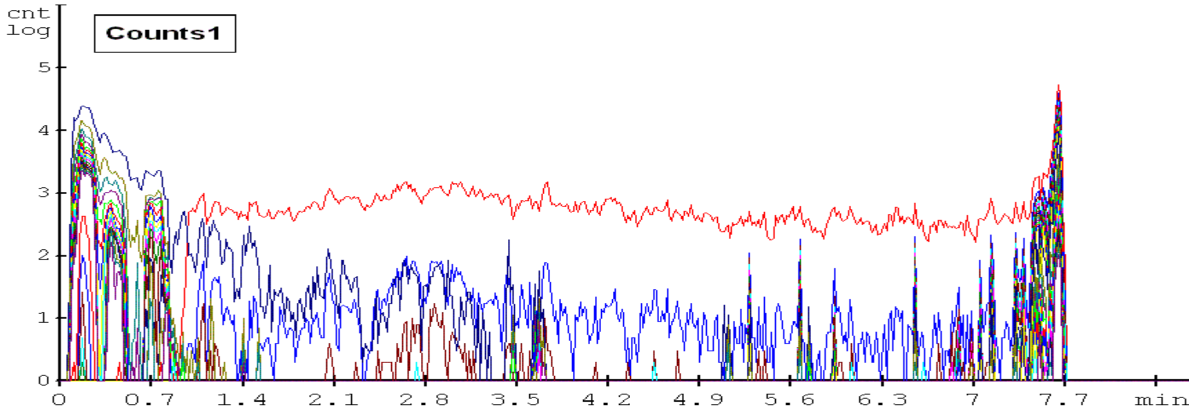

Fig.2 Exemple of AE burst rate in different measured levels of signal – nodular cast iron (final fatigue fracture after app. 5.10 ^{4} load. cycles)

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

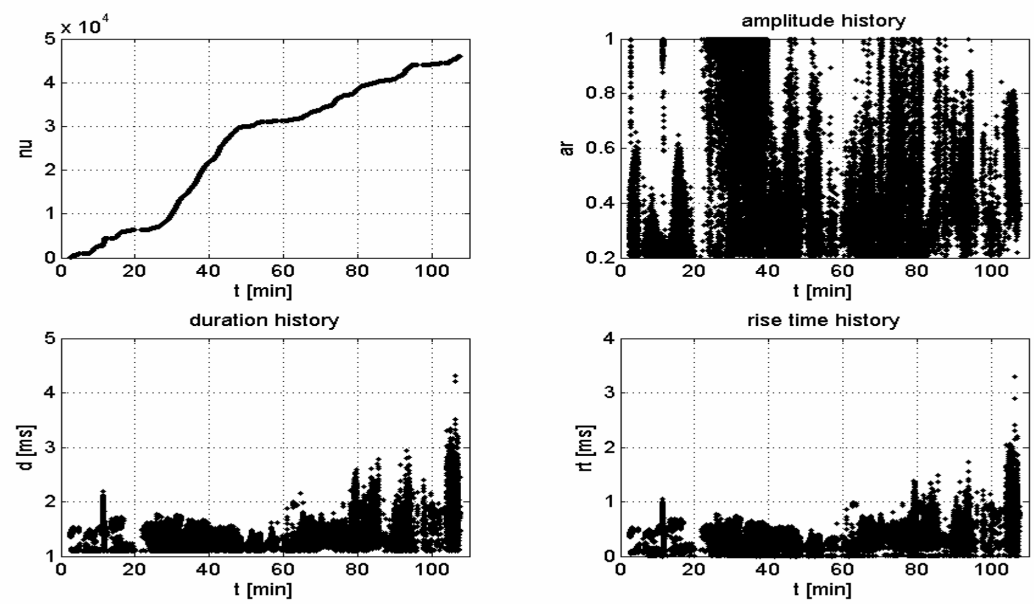

Fig.3 Overwiev of AE events parameters treatment – cumulative number, amplitude, duration and rise time history.

The left top chart shows cumulative number of events across the time. It is approximately possible to divide this feature into three parts with time border of 20 to 50 minutes. The right top chart shows the amplitude course. The effective range was set in order to record events of minimal amplitude, i.e. big amplitudes are cut. A great amount of acoustic emission activity probably lies in the area of 20 to 40 minutes, in some case in the area of 70 to 80 minutes. The left bottom chart shows duration of events. Remarkably longer events are in the end of measurement. The right bottom chart shows the inclination time of acoustic emission.

The correlation AE amplitude graph (Fig. 4) is divided into six time periods. 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.

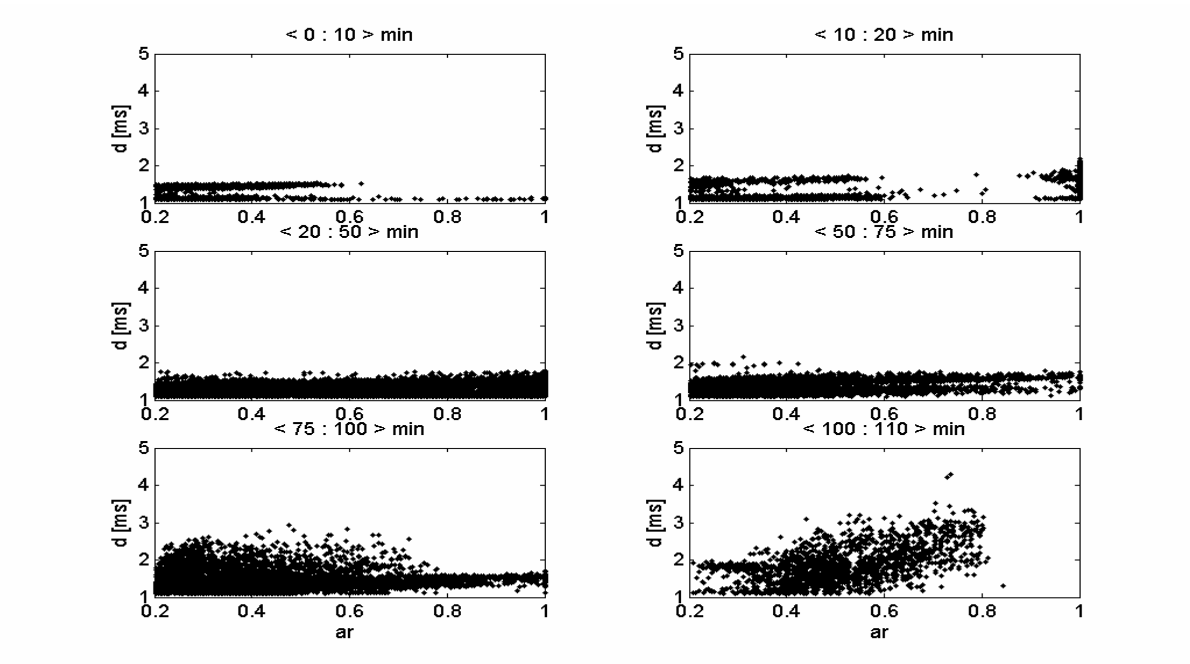

Fig.4 Correlation AE amplitude graphs in differents time periods

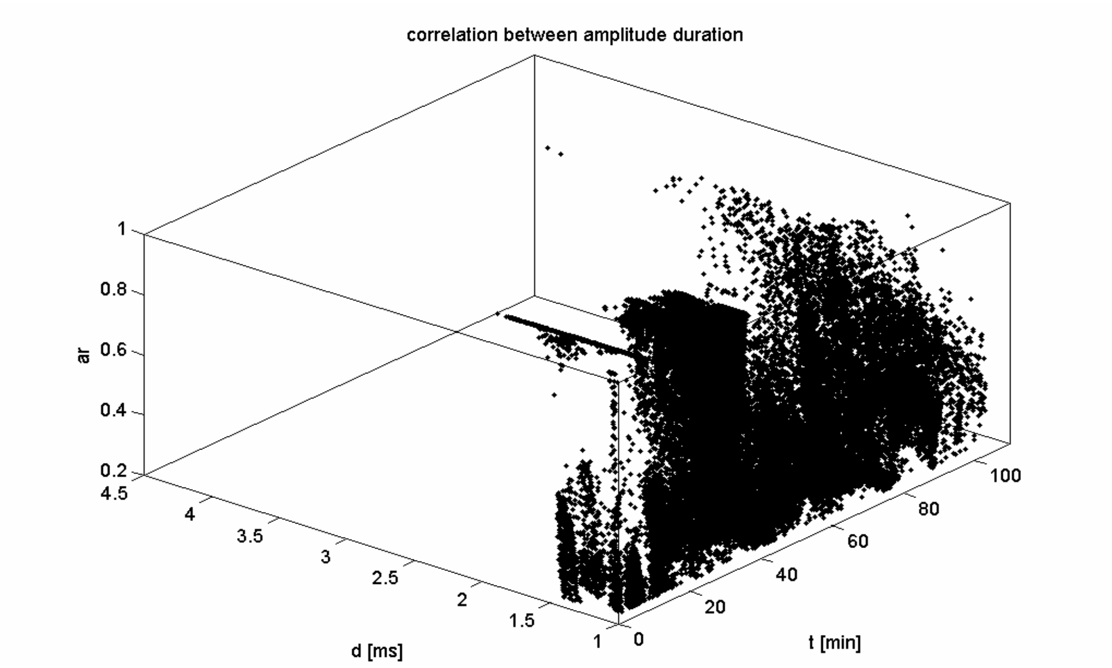

Fig. 5 3D treatment of AE events parameters (time vs. signal duration and relative amplitude)

The time correlation (t) between AE signal duration (d) and its relative amplitude (ar) is figured in a three-dimensional chart (Fig. 5). An interesting course is plotted in time of 10 minutes, where large amplitudes of relatively short duration are recorded.

The other chart in Fig.6 shows statistical distribution of amplitude, evaluated in 1minute intervals from the beginning of its measurement. The „mounts" of low amplitudes 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. Remarkable peaks can indicate the origin or propagation of material failures.

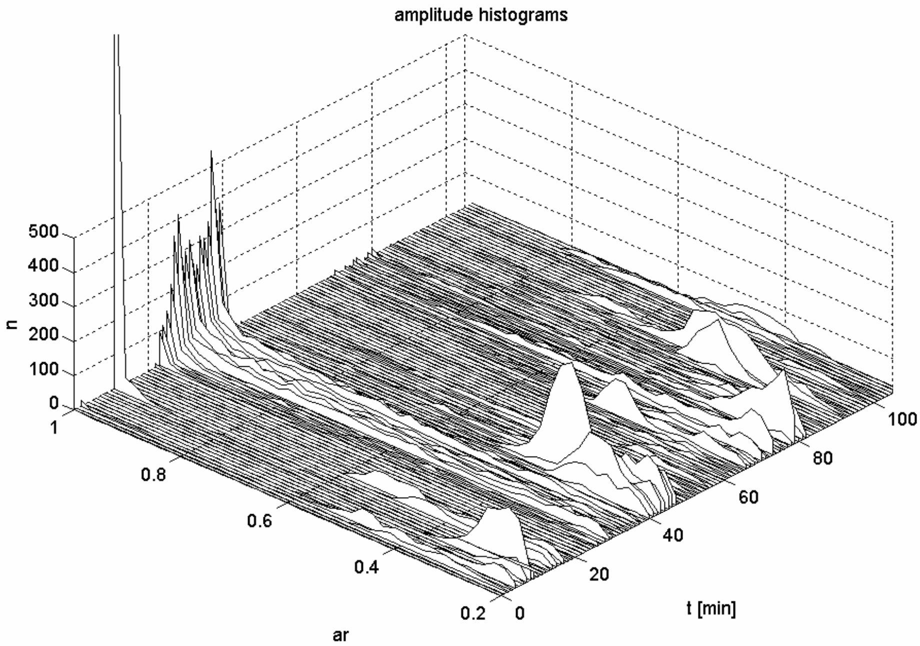

Fig.6 Exemple of statistical distribution of amplitude, evaluated in 1minute intervals.

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.7-10). The following four pictures show charts, displaying realizations and features of recorded AE signals in time of 10, 35, 60 and 100 minutes from the beginning of their measurement. Noted, that these signals were 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).

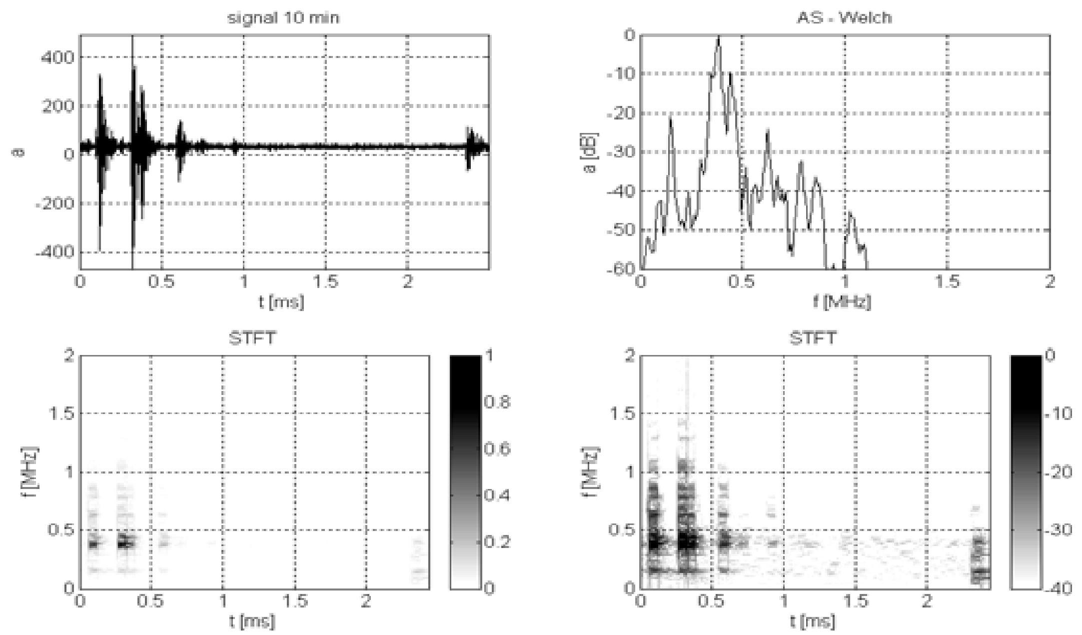

Fig.7 Exemple of AE events with frequency spectrum and Short Time Fourier Transformation – low alloy steel (loading time 10 min.)

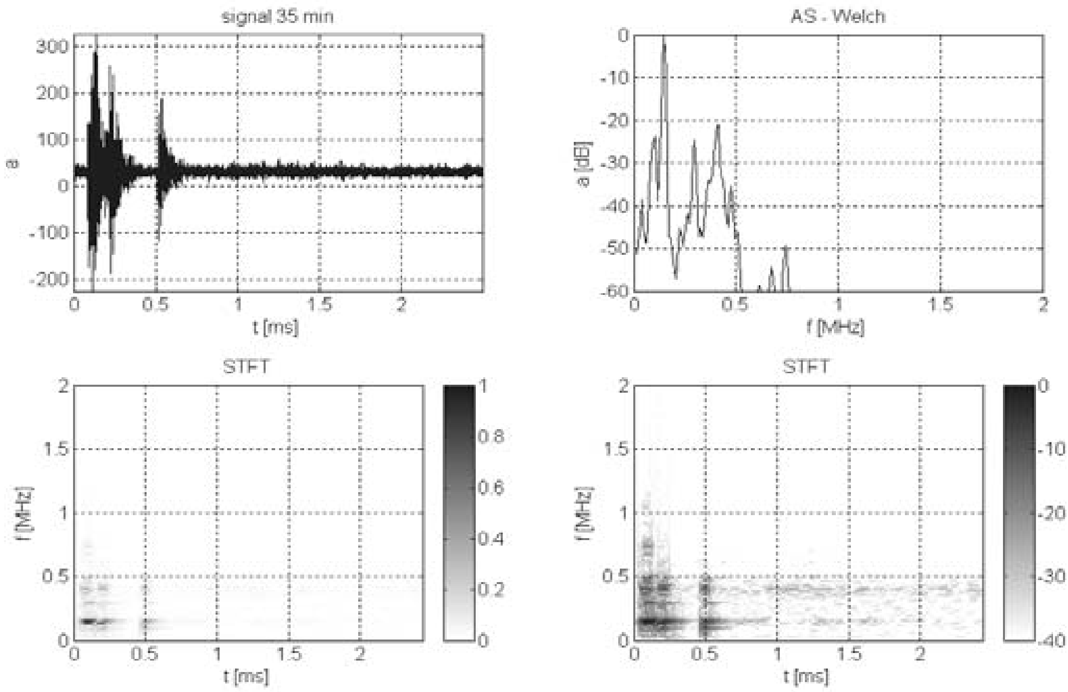

Fig.8 Exemple of AE events with frequency spectrum and Short Time Fourier Transformation – low alloy steel (time 35 min.)

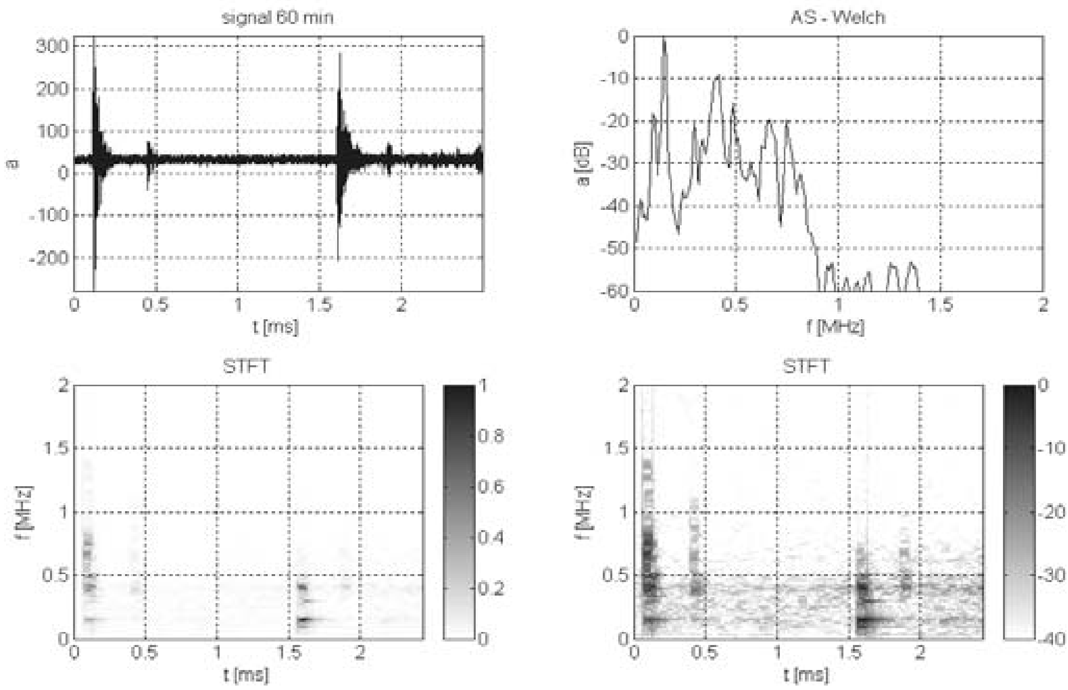

Fig.9 Exemple of AE events with frequency spectrum and Short Time Fourier Transformation – low alloy steel (time 60 min.)

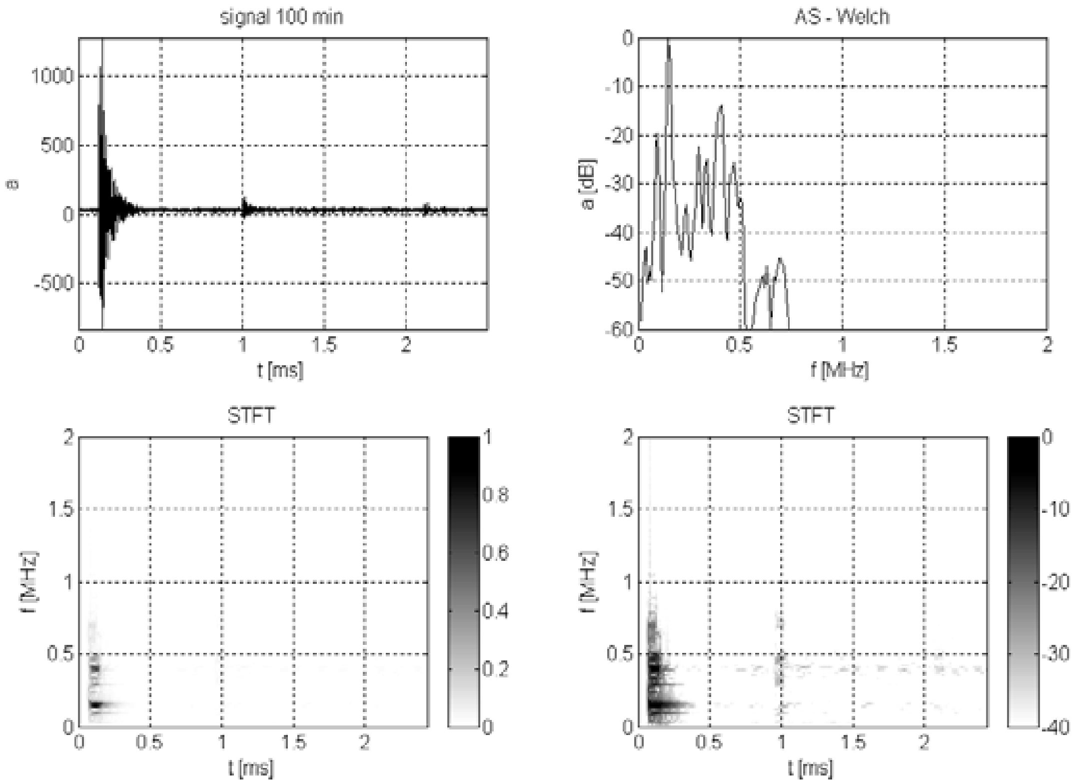

Fig 10 Exemple of AE events with frequency spectrum and Short Time Fourier Transformation – low alloy steel (time 100 min.)

4. Conclusions

Results gained to date show wide possibilities of application of the method of acoustic emission for the identification of fatigue processes. 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. 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.

The fact that every measuring is unique is still a problem, which is caused by very difficult ensuring absolutely identical conditions of every measuring (often long-lasting). In this context, it is necessary to mention a number of factors that have been significantly influencing sensed signal and the possibility of reliable interpretation of the results. Before all, various materials differ significantly in their “acoustic activity” and its character. The signal characteristics of used AE sensors are very important, too. Another decisive factor is the way how the sensing units are gripped on the surface of the sample as well as the transmission medium between the sensor and the surface of the material. 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. 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.

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