Real-Time Acoustic Emission Event Detection with Data Evaluation for Supporting Material Research

Gabor MANHERTZ *, Gabor CSICSO **, Gabor GARDONYI *, Gabor POR **
* Budapest University of Technology and Economics, Budapest, Hungary
** College of Dunaujvaros, Dunaújváros, Hungary

Abstract. The initial aim of the development was to use acoustic emission measurements for material testing of steel. The steel under stress (heat and/or pressure stresses) emits AE signals, which can be detected using AE sensors. Experiments were planned and carried out using a material testing simulator (Gleeble) in the College of Dunaujvaros. Paper presents the software developed under NI LabVIEW Environment for those experiments. The sampling was made with National Instruments PXIe-6363 data acquisition card at 2MHz, which enabled us to process the data real-time deciding if there were AE events in relatively high background. Two real-time event detection methods had been developed: the first uses conventional threshold, the second applies Sequential Probability Ratio Test (SPRT). While threshold method was successfully applied for frequent acoustic events, the SPRT method had advantages in case of rare and weak events.

The parameters of the events had been selected with the aim training and running a fuzzy based expert systems. Besides the traditional AE characteristics (rise time, duration, rate of hits, etc.) we used time and frequency characteristics as well. Frequency parameters were by using FFT algorithms on specially defined event segments. It was shown that AE events exhibit non-Gaussian character. Rate of hits and range of hits were connected to change in the force. The spectra of magneto-acoustic Barkhausen effects (MABE) and AE events were not very different. This is explained by the relatively wide spectral region of the sensors. Measured ultrasound signals could be transferred to audible region.

1. Introduction

Real-Time (RT) acoustic emission measurements are used very often in several research areas. Reference [1] presents a RT system which is capable to analyse and predict failures in slide bearings. Huang et al [2] describe a method specially designed for fatigue and fracture tests. A good method based on an adaptive threshold is presented in [3], which can select friction noises from the background. AE events can be analysed and detected in frequency-domain as well; reference [4] shows a good method for analyzing AE events in frequency domain.

Our main task was to develop a special AE system for supporting material research which will be able to make possible for us to analyse sampled signals using post-processing and later it could be used for RT measurements as well. Moreover, new AE event detection algorithms needed to be implemented, which can detect hits and/or AE events during RT detection or after the sampling process substance-specific AE events with better sensitivity.

The material research experiments were carried out using a Gleeble 3800 (see Pic. 1.) thermomechanical simulator, which has a fully-integrated, digital, closed-loop control system. This simulator is suitable for various physical simulations of manufacturing processes, material tests and for thermomechanical treatments. It was also desirable to have such input channels which could register parallel the time dependent parameters of the experiments.

Pic. 1. The Gleeble 3800 thermomechanical simulator

2. Detecting and Analysing AE Events

We developed a complex system in which it was possible to execute AE measurements and signal post-processing. AE measurement requested high sampling rate therefore it was indispensable to use RT environment.

For this task the best choice was a PXIe embedded system (Pic. 2.) produced by National Instruments. The high baud rate of the PXIe bus allowed us to perform measurements with high sampling frequency A PXIe-8133 Controller was inserted in a PXIe-1065 18-Slot chassis. This controller was sufficiently strong enough (Core i7-820QM 1,73GHz, 2Gbyte DDR3 RAM) to control the high-speed RT operations and the communication with a personal computer via a Gigabit Ethernet port. For the sampling process we inserted an NI PXIe-6363 card into the chassis with a TB-2708 PXI Front-mount SMB Terminal Block. With this hardware setup we could access simultaneously up to 4 channels and up to 2 MS/s sampling frequency on a ± 10V range.

The measuring system was controlled by a personal computer via Ethernet port. This computer sent commands to the PXIe system about the tasks to be carried out. In addition to the control purposes this computer was used to analyze the measured AE signals.

Pic. 2. The measurement system with the NI PXIe embedded computer and a personal computer for control purposes.

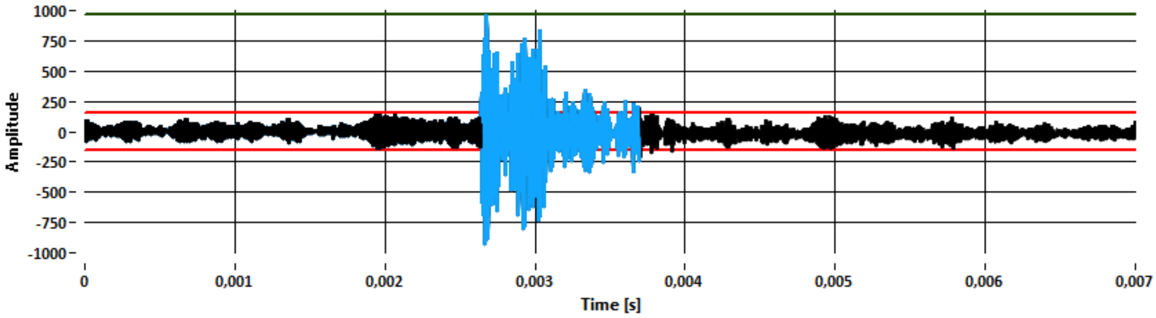
2.1. Algorithms for AE Event Detection

To perform AE event detection, two algorithms were developed. These made us possible to select, cut and save the events occurred in the signal during the material testing. Both of the methods saved the detected event together with time sequences before and after the event. These attached time segments were pre-defined (during our test research, the length of the segments were 0,001s each). These event selecting algorithms could be executed either after the measurement or during the measurement.

2.1.1. Modified Threshold Test

The first algorithm selected those events form the sampled signals which exceeded a pre-defined threshold level. The upper and lower thresholds were estimated as follows. The average of the received data package was calculated. Then the predefined threshold was shifted by the average. E.g. if the pre-defined threshold was 50, but the signal had an offset of 10, then the signal was compared to threshold levels -40 and +60.

The developed method had two modes. In *default mode* the program assumed that an event could be occurred any time on any channel, so each channel was analysed parallel. During the detection, the method kept always in memory the pre-defined time sequences before and after the event, since if an event was occurred, these sequences needed to be saved as well. If it has been detected that the signal exceeded the threshold level on any channel (threshold levels for each channels could be declared separately), the method stepped into *event mode*. The algorithm transmitted the information about which of the channels produced the trigger examining that in details, but no matter in which of the channels the event occurred the given section of the sampled data was saved for all channels. When a data on the examined channel exceeded the threshold level, a decremental counter was set to a value calculated from the width of the pre-defined time sequences and from the sampling frequency. Event was closed if no threshold exceeding happened during this sequence. If the current investigation was within the threshold, the counter was decremented by one, and then the next measured data was examined. If the current tested data did not exceed the threshold, the program started to examine cyclical the data of other channels, while the counter responsible for the length of the additional time sequences (data to data) was decremented continuously. If an event occurred on another channel, its number was saved, and the *event mode* continued its operation on this channel after resetting the counter. If the counter expired, the additional time sequences before and after the event were concatenated into a single array and transmitted as an event for saving.



Pic. 3. The time signal of an event detected by the modified threshold test (blue – the acoustic emission event, black – the additional environment, red – the threshold value (150), green – the maximum amplitude level)

On Pic. 3. an event can be seen which was detected with the threshold method. One can notice, that this method detects only the transversal part of the arriving AE burst. The SPRT detection method presented in the next section is capable to detect the longitudinal component of the events as well.

2.1.2. Sequential Probability Ratio Test

The Sequential Probability Ratio Test (SPRT) invented by Wald [5] is a method, which compares the probability density functions using the ratio of two conditioned probabilities. In the denominator there is the probability which of the samples belong to a process with probability density of hypothesis H_1, while in the nominator we have the probability which of the same samples belong to process with probability density of H_0 hypothesis.

$$\lambda_n = \ln\left(\frac{p(x_1, x_2, \ldots, x_n \mid H_1)}{p(x_1, x_2, \ldots, x_n \mid H_0)}\right) \tag{1}$$

If the set of n samples belongs to stochastic process characterized with H_1 parameters, then the denominator is larger, if the opposite they belongs to (H_0), then the nominator is larger. Consequently the lambda function, which is the logarithm of that ratio, is either growing (H_1 case) or decreasing (H_0 case) at each new sample. We start from zero lambda value and take samples one by one. This is why the method is called sequential. The lambda function is decreasing if the probability density function belongs to (H_0) until it reaches certain decision making level. If the level is set to (-4.6) then the confidence level of the decision is 95%. The same is true for H_1: if the growing value of lambda function exceeds the +4.6 value, then we can state with 95% of confidence level that the stochastic noise belongs to a process with probability density function characterized by H_1 parameters. More, in-depth information about these steps can be found in references [6] and [7]. The method is sensitive for the stochastic part of the signal. Therefore, it is advisable to remove all deterministic parts of vibration signal and it is also advisable to set the mean value to zero. This was achieved in our method using an adaptive autoregressive (AR) [8] filter before applying SPRT.

$$y_k = \sum_{i=1}^{M} a_i y_{k-i} + w_k \tag{2}$$

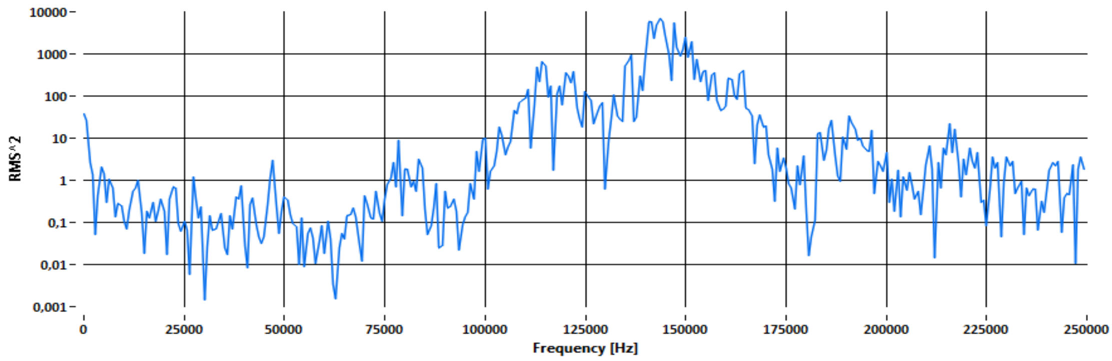
where y_k are the sampled signal, a_i are the autoregressive coefficients, w_k is the stochastic noise contribution to the signal and M is the model order. Based on this formula, autoregressive coefficients can be estimated for the given sampled signals and a SPRT pre-filter can be built (where x_j are the actual samples of the signal):

$$\widetilde{x_j} = x_j - \sum_{i=1}^{M} a_i x_{k-i} \tag{3}$$

2.2. Post-processing the AE Events

Besides the event detection algorithms a post-processing system was developed. This program was designed to analyse the registered time signal of AE measurements.

After the preparation of the signal it was possible to retrieve statistical parameters (mean, standard deviation, variance, skewness, kurtosis, RMS), histogram and classical AE parameters (rate of hit, rise time, duration, count, maximum amplitude) too. If the RT data processing did not find any event during sampling we could carry out still “off-line” AE event detection using methods mentioned above. When the original detection processes (threshold and SPRT) have been finished, the resulted event signals could be loaded into this system as well to analyse them. Finally, frequency characteristics of the AE events could be estimated with an FFT algorithm using Hanning-window (Pic. 4.). To make it possible to listen the measured ultrasound signal we developed a software part which is able to transfer the signal to audible range with the modification of the sampled signal's *dt*.

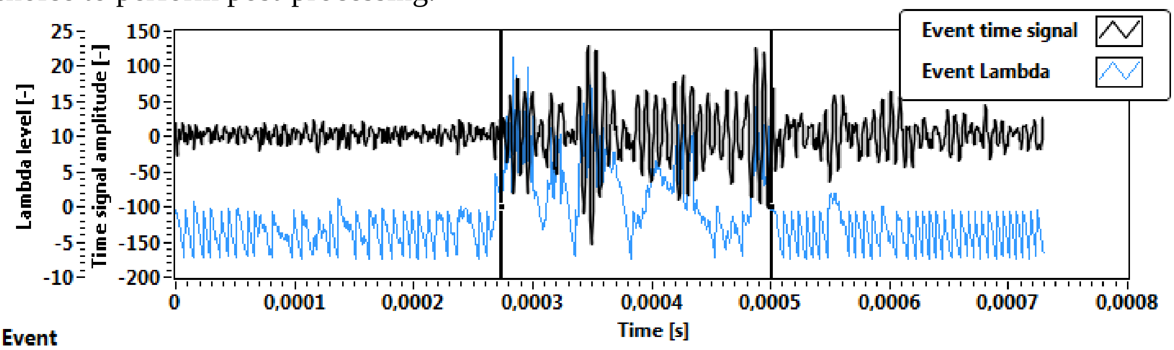


Pic. 4. An example for FFT spectra calculation of an event

3. Testing the system in real measurements

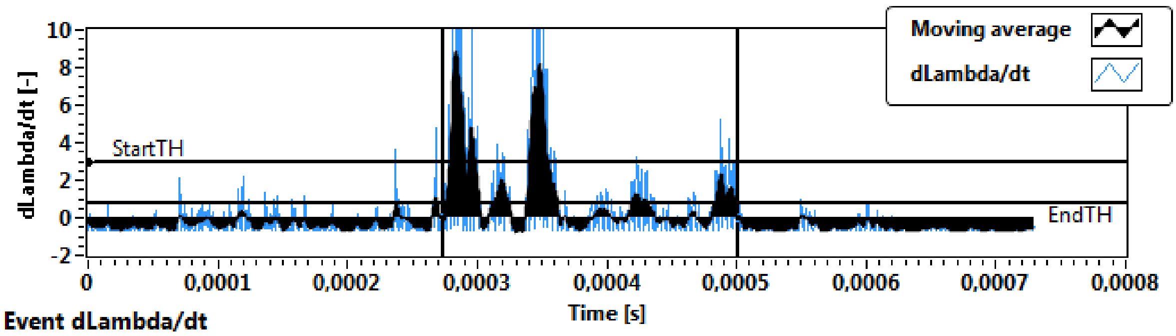
To test our system in reality experiments were preformed on a Gleeble 3800 simulator, where low cycle fatigue test were being carried out. The test material was an ordinary austenitic material (08H18N10T). Details and physical results are discussed in [9] presented at this conference. Here we present those results which reflect the ability of our system. Two A-15 AM AE sensors were attached to the Gleeble's two wedges using their integrated magnets with oil couplant. The sampling processes were executed with 1MHz sampling frequency in a ±1V range.

After the fatigue test of the material SPRT event detection algorithm and several parameter query methods were executed on the measured signal off-line. We used SPRT because after the inspection of the measured signal it was noticed that the amplitudes of the events are very low, moreover, they were almost buried in the noise. Since the distributions of the events may differ from the distribution of the background, the SPRT was the best choice to perform post-processing.



Pic. 5. Demonstration of the SPRT selecting a burst, when lambda function partly or meanly positive

On Pic. 5. the selected start and end of the event is indicated. It is important to define those if one would like to estimate typical AE parameters shown in Table 1. The start and end of the event is set by us not at the time, when the lambda/dt value exceeded its threshold levels, but we set the start of the event when lambda/dt changes its sign last time before it exceeds "StartTH" level. The event ends, when lambda/dt changes its sign last time after going under the "EndTH" level (see Pic. 5. and Pic. 6.). The time signal between these boundaries serves for the calculation of statistical and AE parameters.



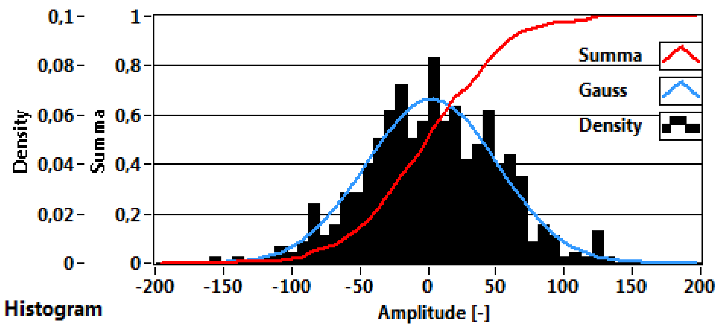
Pic. 6. The real start and end selection using SPRT in our system.

Table 1. Parameters of the event on Pic. 5.

Start time [s]	Duration [s]	Range [-]	Max [-]	Rise time [s]	RMS [-]
39,61824	0,000227	284	154	0,000075	48,03506

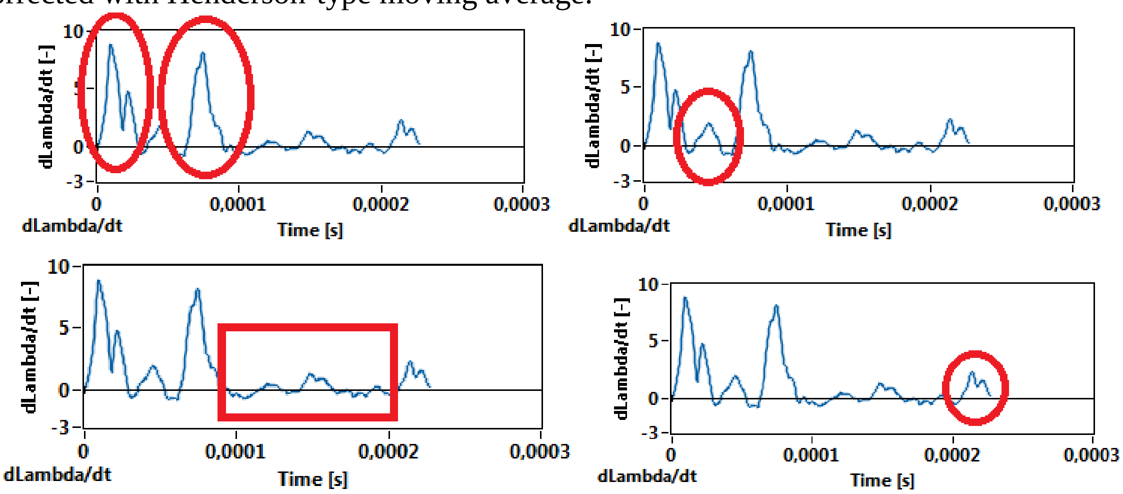
Count [-]	Mean [-]	Deviation [-]	Variance [-]	Skewness [-]	Kurtosis [-]
68	2,993407	47,99447	2303,469	-0,03441	0,012777

A typical histogram of an event can be seen on Pic. 7. Based on the statistical parameters and the generated graph, we can state that the typical amplitude distribution function of an event deviates from Gaussian.



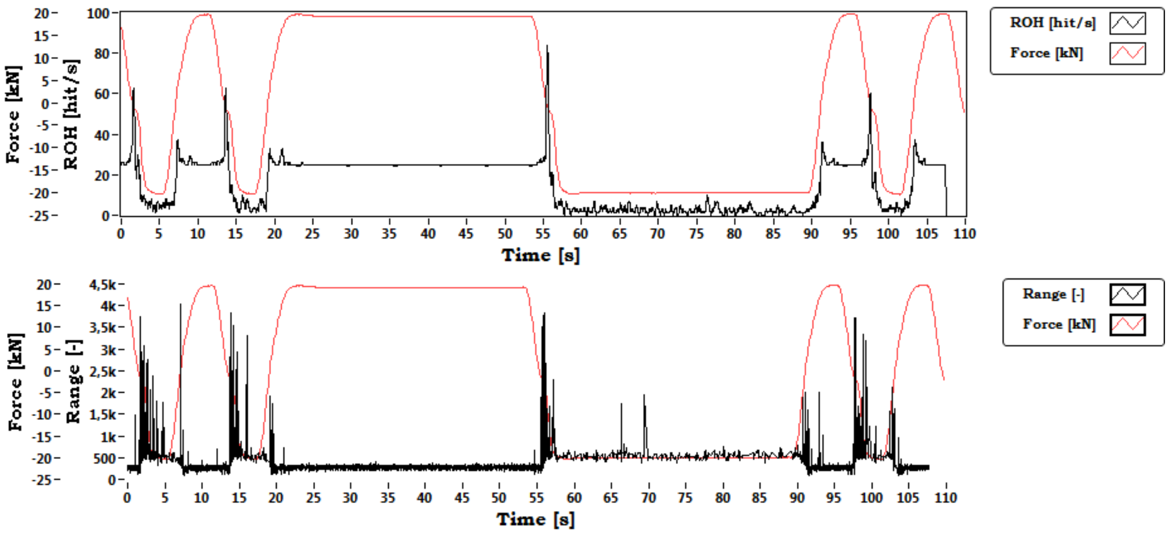
Pic. 7. Typical amplitude distribution function of an event.

On Pic. 8. the typical form of the lambda/dt function can be seen. The function was corrected with Henderson-type moving average.



Pic. 8. Typical form and phenomena of the lambda/dt function of an event corrected with moving average (red indicators are typical phenomeas)

At the beginning of the event two major protrusions can be seen. The first one had usually larger amplitude and two secondary branches. In case of the second one, the branches could be separated, but often they were blurred due to the averaging method. Between these two peaks a smaller one appeared always. Usually between the three discussed peaks the function had negative values on two sections. In the middle section of the lambda/dt function the values were close to zero (fluctuation around zero) but their discrimination was not as clear as in the previous cases. In the majority of the events a peak could be seen after 0,0002 [s], with amplitude smaller than the first ones, but the twin-peaked nature was observed here as well.



Pic. 9. Rate of hits and amplitude of hits estimated by our system during experiment. Red line is the force during fatigue test, while the black curve shows the rate of hit measured by our system

One can see on Pic. 9., that the rate of hits or the range of hits function could be even used to notice where the force had been changed. When the direction and the magnitude of the load were changed, the count of the acoustic emission events changed as well as the maximum amplitude of the events. Besides, differences could be seen in the rate of hits between the pulled and pressed sections - there were more events during pulling.

The results showed that the SPRT method is absolutely suitable for AE event detection during fatigue test.

4. Conclusion

The newly developed acoustic emission system recognizes AE hits using on one hand a modified threshold method and on other hand a brand new idea of using Sequential Probability Ratio Test. This is more suited for those events, which may occur in metals under stresses, mainly in laboratory examination, but also in industrial application. It has been shown [9] that the use of the SPRT methods allows not only high sensitivity but a selection of those hits, which have been coming from acoustic Barkhausen emission and from stress born acoustic emission. Besides conventional AE parameters high sampling rate enabled us to produce auto power spectral density of hits or events. New functions have been also developed: amplitude distribution function (histogram) seems to be sensitive for different sources, thus it might be a new classification method for event in the near future; skewness and kurtosis may help in classification as well. Localization algorithm included in the program is not a new idea, but in combination with the aforementioned parameter estimation it gives information of the nature of the emission, since it can be combined with temperature distribution as well.

Acknowledgment

This work was carried out in Hungarian Acoustic and Industrial Diagnostic Testing Laboratory (MAIDLab) of the College of Dunaujvaros. The work was supported by the TAMOP-4.2.2.A-11/1/KONV-2012-0027 project. The project is co-financed by the European Union and the European Social Fund.

References

[1.] Baran I, Nowak M, Darski W (2007) Application of Acoustic Emission in Monitoring of Failure in Slide Bearings. 25:341-347

[2.] Huang M, Jiang L, Liaw PK, Brooks CR, Seeley R, Klarstrom DL (1988) Using Acoustic Emission in Fatigue and Fracture Materials Research. The Minerals, Metals & Materials 50(11)

[3.] Barat V, Grishin D, Rostovtsev M (2011) Detection of AE Signals Against Background Friction Noise. J. Acoustic Emission 30:133-141

[4.] Ito K, Enoki M (2007) Real-Time Denoising of AE Signals by Short Time Fourier Transform and Wavelet Transform. J. Acoustic Emission 25:247-252

[5.] Wald A (1945) Sequential Tests of Statistical Hypotheses. Annals of Mathematical Statistics 16:117-186

[6.] Deak T (2009) The usage of the SPRT algorithm in real-time, Paper for the Student Research Conference, College of Dunaújváros

[7.] Szappanos G, Por G. (1998): Improvement in the theory of identification of Burst-Shaped Events for Fault Diagnosis. Nuclear Science and Engineering 130:261-267

[8.] Box GEP, Jenkins GM (2008) Time Series Analysis: Forecasting and Control, 4th edn. Wiley, New York

[9] Por G, Fekete B, Csicso G, Trampus P (2014) Acoustic Events during Fatigue Test of Structural Steels EWGAE 2014 Dresden, [paper We.4.B.4. manuscript submitted for review]