Ročník 2010 electroscope Číslo III

Electromagnetic and Acoustic Emission Signals Continual Measurement and Real Time Processing

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Abstract:
Stochastic electromagnetic and acoustic emission signals may be observed when the solid dielectric materials are mechanically stressed. Study of these signals may be used for indication of micro-crack formation in stressed materials. This paper describes the methodology, which was developed specially for electromagnetic and acoustic emission signals continual measurement and real time processing.

INTRODUCTION

Application of mechanical stress leads to micro-cracks formation in stressed solid dielectric materials. Cracks generation is accompanied by generation of the electromagnetic (EME) and acoustic (AE) emission signals, which can be measured by appropriate sensors. The main advantage of EME and AE stochastic signals is the fact, that they are detected already in stressed stage, which prevents the macroscopic dislocation in solids. More information about the EME and AE phenomenon is available in literature [1].

The measured samples were prepared from EXTREN 500 composite material. This composite material consists of a combination of fiberglass reinforcement and a resin binder [2]. The applied mechanical stress was perpendicular to the reinforcing fiberglass direction.

Suitably designed methodology of EME and AE signals measurement, processing and evaluation allows to observe the stressed materials response to applied mechanical load continuously and also allows to obtain the useful information about the processes taking place in the cracks formation in solids.

MEASUREMENT SYSTEM

A new fully automated set-up for EME and AE signals measurement (Fig. 1) was developed in our department (FEKT UFYZ). This new measurement system is based on the PXI platform, which is one of the most extended modular platforms for measurement and automation systems. The hydraulic press provides the specimen mechanical load in the range of 10 kN to 200 kN. Actual mechanical load is measured by the very precise tenzometer. It provides actual mechanical load linear convert to the output voltage (1 mV ~ 20 kN) and it must be powered by 5V DC voltage. The EME channel consists of a capacitance sensor which dielectric is formed by the stressed sample, a high pass-filter-type load impedance ZL, a low-noise preamplifier and an amplifier (if it’s necessary). A total EME channel gain is 40 or 60 dB. The AE channel consists of a piezoelectric acoustic sensor (30 kHz ~ 1 MHz) and an amplifier with gain of 40 dB. In case of the AE signal multi-channel measurement, we can use this redundancy information for the crack localization (EME + 3 up to 8 AE channels).

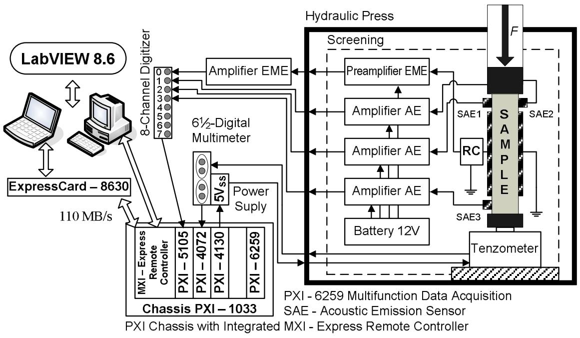


Fig. 1: Designed experimental set-up

EME Preamplifier (3S SEDLAK PA31)

This low-noise EME signal preamplifier offers 20 Hz to 10 MHz bandwidth, high input impedance 2 × 10 MΩ / 20 pF, variable gain 6 / 20 / 40 dB and producer guaranteed noise voltage < 1,8 nV / √Hz.

AE Amplifier (3S SEDLAK PA15)

It is used for AE signal forcing and specific parameters are: 3 Hz to 1 MHz bandwidth (sufficient for AE signals), high input impedance 2 × 10 MΩ / 40 pF, variable gain 0 / 20 / 40 dB and noise voltage < 2 nV / √Hz.

AE sensors

The piezoelectric sensors from different vendors are used for AE signals scanning. These sensors meet the requirements of the AE signal frequency band (at least up to 1 MHz).

EME sensor

The capacitance sensor is commonly used to EME signal capture. In our case, the capacitance sensor is formed by the specially made adjustable bracket with two electrodes, into which we can easily insert the rectangular samples from studied material.

DESIGNED PXI SYSTEM

The main part is composed by specific PXI system, which offers the maximal flexibility and mobility of whole designed measurement system. Efficient modular PXI system must be able to provide continual multi-channel data acquisition, power sourcing of the tenzometer, continual tenzometer output voltage reading and eventually, the hydraulic press mechanical load regulation. The advanced requirement is the possibility of PXI system remote control by the laptop computer. It is useful in the cases, when we want to utilize our set-up out of our laboratory. Finally, the PXI system must by sufficiently universal for other applications then just EME and AE signals measuring. Designed PXI system consists of the following components:

NI PXI-1033 (Chassis),
NI PXI-5105 (8-Channel Digitizer),
NI PXI-4072 (Digital Multimeter),
NI PXI-4130 (Power Source),
NI PXI-6259 (Multifunction Data Acquisition),
NI ExpressCard-8630 (Laptop control of PXI).

Detailed information about the designed measurement system is available in literature [3].

The complex software package was developed in the LabVIEW environment. It allows controlling the PXI system modules, finding the typical events in the individual data channels, saving these events as separate files and describing their basic parameters (event start/end time, maximal amplitude, RMS value, energy, etc.). Processing and evaluation of these parameters is taking place simultaneously (in real time) with the process of measurement.

AE PARAMETERS

In case of acoustic emission, the proposed parameters were inspired by the technical standard for acoustic emission (ČSN EN 1330-9). The user can observe the time behavior of detected signals on all active AE channels, including a calculated envelop (Fig. 2) and a table with the quick overview of all found parameters (Fig. 3). The following parameters are detected for the signals with zero mean:

Peak Amplitude → This parameter is calculated according to the formula

$$x_{\mathrm{m}} = \frac{x_{\mathrm{MAX}} - x_{\mathrm{MIN}}}{2} \quad [\mathrm{V}], \tag{1}$$

where x_{MAX} and x_{MIN} is the maximum and minimum signal value.

Start Time → Firstly we need to estimate the event noise background x_{N1} from the first ten percent measured realization samples (the maximum value from these samples). Then we find the signal maximum amplitude

$$x_0 = \max\{x_{\mathrm{MAX}}, |x_{\mathrm{MIN}}|\} \quad [\mathrm{V}]. \tag{2}$$

AE event beginning threshold is then calculated by the formula

$$x_{\mathrm{T1}} = \frac{(x_0 - x_{\mathrm{N1}})}{100} \cdot P + x_{\mathrm{N1}} \quad [\mathrm{V}], \tag{3}$$

where P is a user selectable value indicated in %, which can vary depending on the nature of the measurement (in our case experimentally set to 5). Event start is determined as a time t_1 of first crossing the threshold into an envelope signal.

Stop Time → The AE event end threshold is calculated by the formula

$$x_{\mathrm{T2}} = \frac{(x_0 - x_{\mathrm{N2}})}{100} \cdot P + x_{\mathrm{N2}} \quad [\mathrm{V}], \tag{4}$$

where x_{N2} is estimated from the last ten percent of measured realization samples. Parameter P can also be changed by a user (default is 20). Event end is defined as time t_2 to the first decrease of the signal envelope below the threshold x_{T2}.

Event Duration → The event duration is simply determined by the difference

$$t_{\mathrm{E}} = t_2 - t_1 \quad [\mathrm{s}]. \tag{5}$$

Rise Time → The event rise time is defined like

$$t_{\mathrm{R}} = t_{\mathrm{MA}} - t_1 \quad [\mathrm{s}], \tag{6}$$

where t_{MA} is time of achieving the signal maximum amplitude x_0.

Count → Parameter N_0 indicates the number of crossings through the signal zero level during the event duration t_{E}.

Count to peak → Parameter N_1 indicates the number of crossings through the signal zero level in the time interval t_{R}.

Average Frequency → The average frequency of crossings during the event duration.

$$f_{\mathrm{avg}} = \frac{N_0}{2} \cdot \frac{1}{t_{\mathrm{E}}} \quad [\mathrm{Hz}]. \tag{7}$$

Event RMS → The event RMS value is obtained from relation

$$x_{\mathrm{RMS}} = \sqrt{\frac{1}{N}\sum_{i=0}^{N-1} x_i^{\ 2}} \quad [\mathrm{V}]. \qquad (8)$$

Event Energy → The event energy is defined as

$$E_{\mathrm{E}} = \Delta t \cdot \sum_{i=0}^{N-1} x_i^{\ 2} \quad [\mathrm{V}^2.\mathrm{s}], \qquad (9)$$

where Δt denotes the signal sampling period.

Event Dominant Frequency → The dominant frequency from the measured realization.

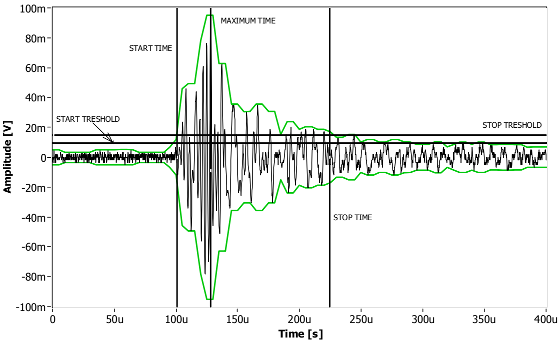
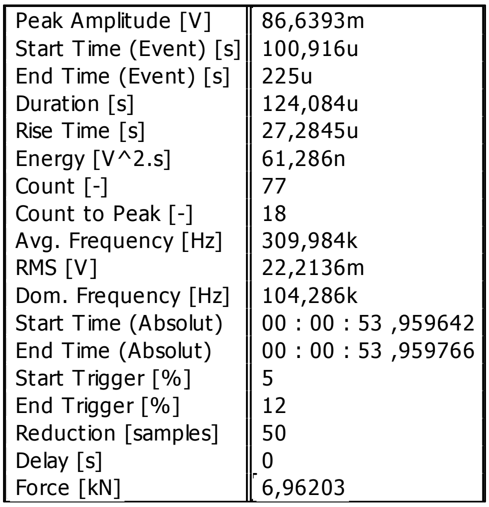


Fig. 2: Time behavior of detected AE signal



Peak Amplitude [V]	86,6393m
Start Time (Event) [s]	100,916u
End Time (Event) [s]	225u
Duration [s]	124,084u
Rise Time [s]	27,2845u
Energy [V^2.s]	61,286n
Count [-]	77
Count to Peak [-]	18
Avg. Frequency [Hz]	309,984k
RMS [V]	22,2136m
Dom. Frequency [Hz]	104,286k
Start Time (Absolut)	00 : 00 : 53 ,959642
End Time (Absolut)	00 : 00 : 53 ,959766
Start Trigger [%]	5
End Trigger [%]	12
Reduction [samples]	50
Delay [s]	0
Force [kN]	6,96203

Fig. 3: Table of all found parameters

EME PARAMETERS

In the case of EME signal is necessary to define the appropriate parameters with regard to the considerable variability of these random signals. In the current version of the measurement program only following parameters are evaluated:

Start Time → Procedure is the same as in the AE Start Time parameter with the difference, that the signal envelope is not available here. EME event start is determined as the time of the first crossing the threshold into the actual realization.

Maximum Amplitude → The EME signal maximum value.

Dominant Frequency → The EME signal dominant frequency.

FURTHER PARAMETERS

Time Delay (between EME and AE signals) → This parameter can be calculated easily from the EME and AE events beginnings (EME and AE Start Time parameters). In case of the AE signal multi-channel measurement, we can get the useful information about the crack position in the stressed material.

Crack Distance (from the AE sensor) → It can be calculated from the found Time Delay and the acoustic signal propagation velocity in the studied material.

PROCESSING AND EVALUATION

Fig. 4 shows the characteristics that the user can monitor during the real-time measurement (actual mechanical load and corresponding acoustic emission events intensity). The events intensity increases at the moments, which corresponds to the mechanical load step changes and events intensity reaches the maximum just before the sample destruction.

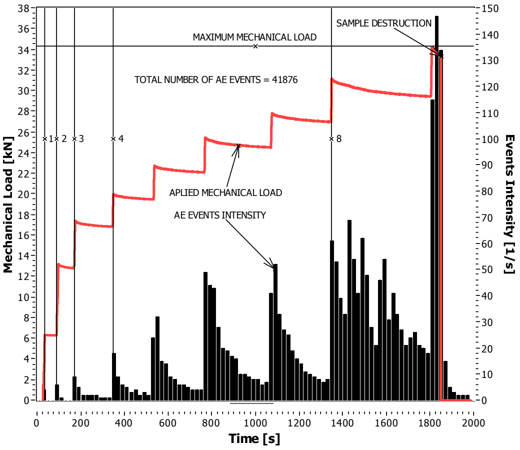


Fig. 4: Example of stressed materials response to applied mechanical load in real time

After finishing the measurement we have files with the events parameters recorded in the individual channels. Due to these parameters, many various progresses may be traced during the time period, while the mechanical load was applied.

Fig. 5 illustrates the stressed sample response (corresponding AE event intensity) to the fixed load value (the fifth section of Fig. 4) and Fig. 6 shows the detail of applied mechanical load in this section.

In the Fig. 7 and Fig. 8 it is possible to see the dependences of two fundamental parameters of AE signal in time (after setting the defined load).

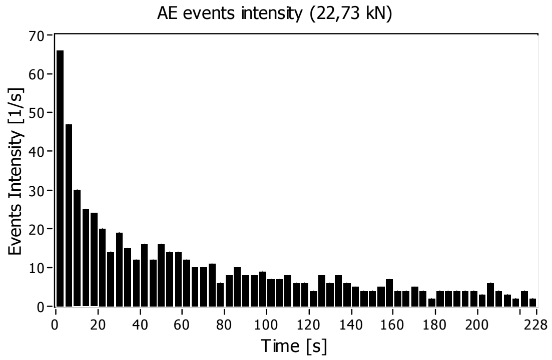


Fig. 5: AE event intensity (22,73 kN)

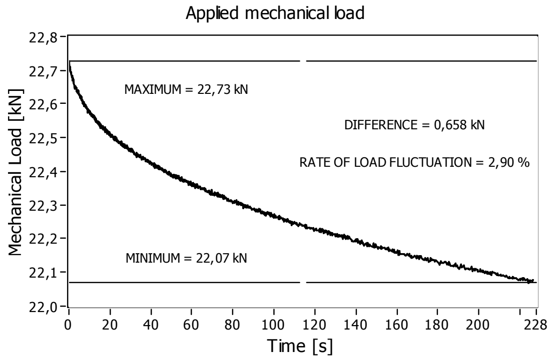


Fig. 6: Applied mechanical load

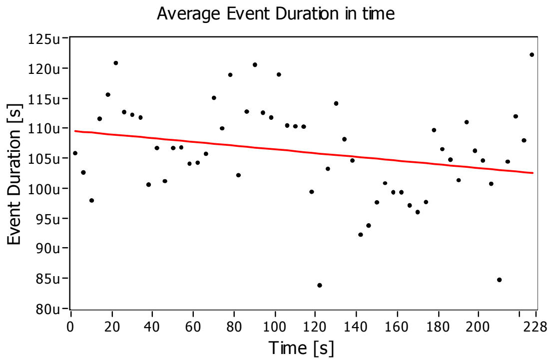


Fig. 7: Average Event Duration in time

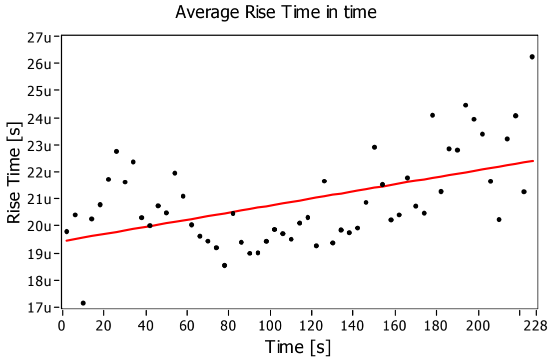


Fig. 8: Average Rise Time in time

CONLUSION

Electromagnetic and acoustic emission signals may be used for indication of crack formation in stressed solid dielectric materials. The new improved set-up was developed for these signals continual measurement. Designed measurement system is based on the modern PXI platform. This new measurement system offers continual measurement, real-time processing and evaluation of electromagnetic and acoustic signals and it is completely controlled by the National Instruments LabVIEW graphical programming environment.

Appropriate parameters have been proposed to describe the typical EME and AE signals. Processing and evaluation of these parameters is taking place simultaneously (in real time) with the process of measurement. Thanks to continuously detected parameters of both signals will be possible to study the cracks parameters time dependence during the defined load characteristics.

The practical application of the developed methodology may be utilized for the diagnostics of the dielectric solid materials under mechanical stress and particularly for study of the material cracks formation, evolution and localization.

ACKNOWLEDGMENTS

This research has been supported by the Grant Agency of the Czech Republic within the framework of the projects GACR 102/09/H074 "*Diagnostics of material defects using the latest defectoscopic methods*", FEKT-S-10-4 "*Research of methodologies for improvement the optoelectronic materials and devices quality*" and MSM 0021630503 Research Intention MIKROSYN "*New Trends in Microelectronic System and Nanotechnologies*". This support is gratefully acknowledged.

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