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POTENCIALS OF SAP FLOW EVALUATION BY MEANS OF ACOUSTIC EMISSION MEASUREMENTS

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Abstract

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The work deals with measurement techniques of water conducting system in the trees. Water conducting system (including xylem and phloem) indicates its importance for related physiological processes. There are still problems how to measure its functioning (which variables and how), especially in the open field (e.g., forests and orchards) in order to get maximum information about it. Simple band dendrometers measuring seasonal dynamics of stem growth have been already applied for many years, being gradually replaced by their more sophisticated electronic versions most recently. The sap flow is a suitable variable, because it links roots and crowns and provide information about transporting the largest amount of mass in plants, which can be decisive for their behavior. Following pioneering work in the last century (Huber, 1932), many types of sap flow measurement methods based on a variety of principles (e.g., thermodynamic, electric, magneto-hydrodynamic, nuclear magnetic resonance, etc.) have been described.

Only a few of these, particularly those based on thermodynamics, have been widely used in field-grown trees. E.g., heat pulse velocity system developed by Green (1998) and Cohen *et al.* (1981). Heat ratio method also works with pulses, but interpreted the data in more sophisticated way (Burgess, 2001). Widely used is a simple heat-dissipation method (Granier, 1985). Direct electric heating and internal sensing of temperature was applied in the trunk heat balance method (Čermák *et al.*, 1973, 1976, 1982, 2004; Kučera *et al.*, 1977; Tatarinov *et al.*, 2005). The heat field deformation method is based on measurement of the deformation of the heat field around a needle-like linear heater (Nadezhdina *et al.*, 1998, 2002, 2006; Čermák *et al.*, 2004).

Another important variable is water potential, which could be measured in the past only periodically on selected pieces of plant material using pressure (Scholander) bomb, but most recently also continuous measurements became possible due to application of psychrometric method (Dixon and Tyree, 1985). There exist also other physical variables carrying important information, which can be measured using different principles. This includes e.g., acoustic methods, which can detect quantitative variation of pulses occurring during cavitation events, associated with interruptions of water columns in vessels. This must not necessarily be a single source of acoustic emissions. In this study we are focused on a general description of acoustic events measurable in a wide range of their spectrum. The first aim was to detect such signals and the second to learn them and gradually analyze in order to better understand the associated processes causing their occurrence and their relations to plant life.

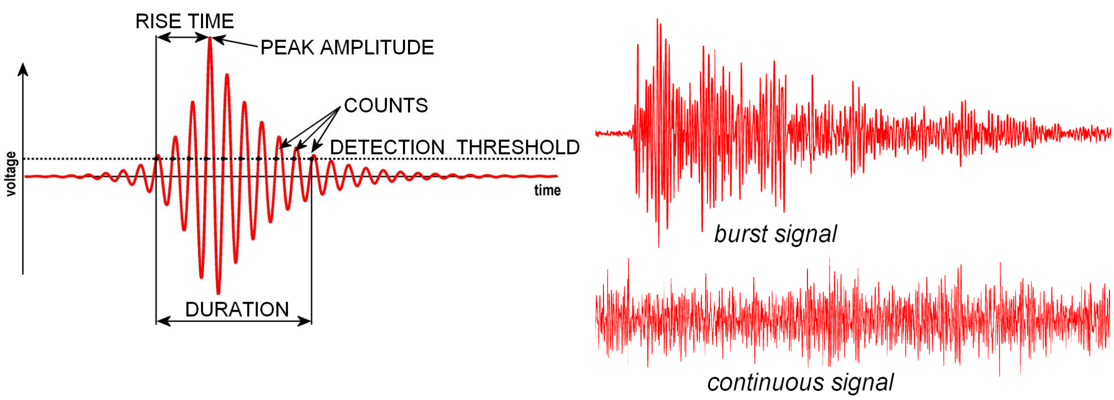
acoustic emission, AE, sap flow, waveguide

"Acoustic emission (AE) is a physical phenomenon whereby transient elastic waves are generated within a material or by a process" (EN 13554, 2011). AE is the term used when defects in materials rapidly release energy when subjected to mechanical loading. This released energy propagates in form of high frequency stress waves on the surface of the tested structure and there the waves are detected by the use of sensors that convert the particle motion into electric signals. These signals can be of a burst or continuous nature and are processed by appropriate instrumentation to detect, characterize and locate the AE sources. Fig. 1 shows the basic signal parameters and types of AE signal. The AE analysis is the characterization of the bursts according to intensity and frequency content.

The application of load or harsh environment in a material produces structural modifications such as plastic deformation, crack propagation, corrosion, erosion and phase transformations. AE sources also arise from impact, turbulent flow, friction, cavitations, electric discharge etc. All these mechanisms and processes are generally accompanied by the generation of elastic waves and these waves therefore contain information on the internal behaviour of the material and/or structure and on the wave sources nature.

AE method is used successfully in a wide range of engineering applications including: detecting and locating defects in pressure vessels, corrosion or leakage in storage tanks and pipeline systems, monitoring welding applications, corrosion processes, concrete failure control, continuous monitoring of large construction works, detection of wire ruptures on cables (bridges stays), partial discharges from components subjected to high voltage and more.

The first report from the area of application of audible acoustic emission in the area of plants was published in 1966 by J. A. Milburn and R. P. C. Johnson (Milburn and Johnson, 1966). Introduction of ultrasonic acoustic emission into the investigation of plants (begin. of eighties) meant significant progress in identifying sources of AE (Tyree and Dixon, 1983). It was proved that changes of AE signals are attributable to local disruptions of the water columns and an uninterrupted flow of water is only conceivable if the embolism defects are continuously being repaired. Very interesting researches focused on identification of AE sources in transpiring plants were presented at 2004 (Laschimke *et al.*, 2004). The authors stated that „the AE from plants do not necessarily occur in conjunction with water stress. The frequency pattern and the waveform in the various signals show that AE may possibly be generated by still unknown hydraulic events, more complex than "cavitations". Authors created a transport model,



1: *AE signals parameters and basic types of signal*
Source: Authors

2: *Placement of AE sensors on the tree on steel blade (a) and on waveguide (b) – left, final arrangement of test – right*
Source: Authors

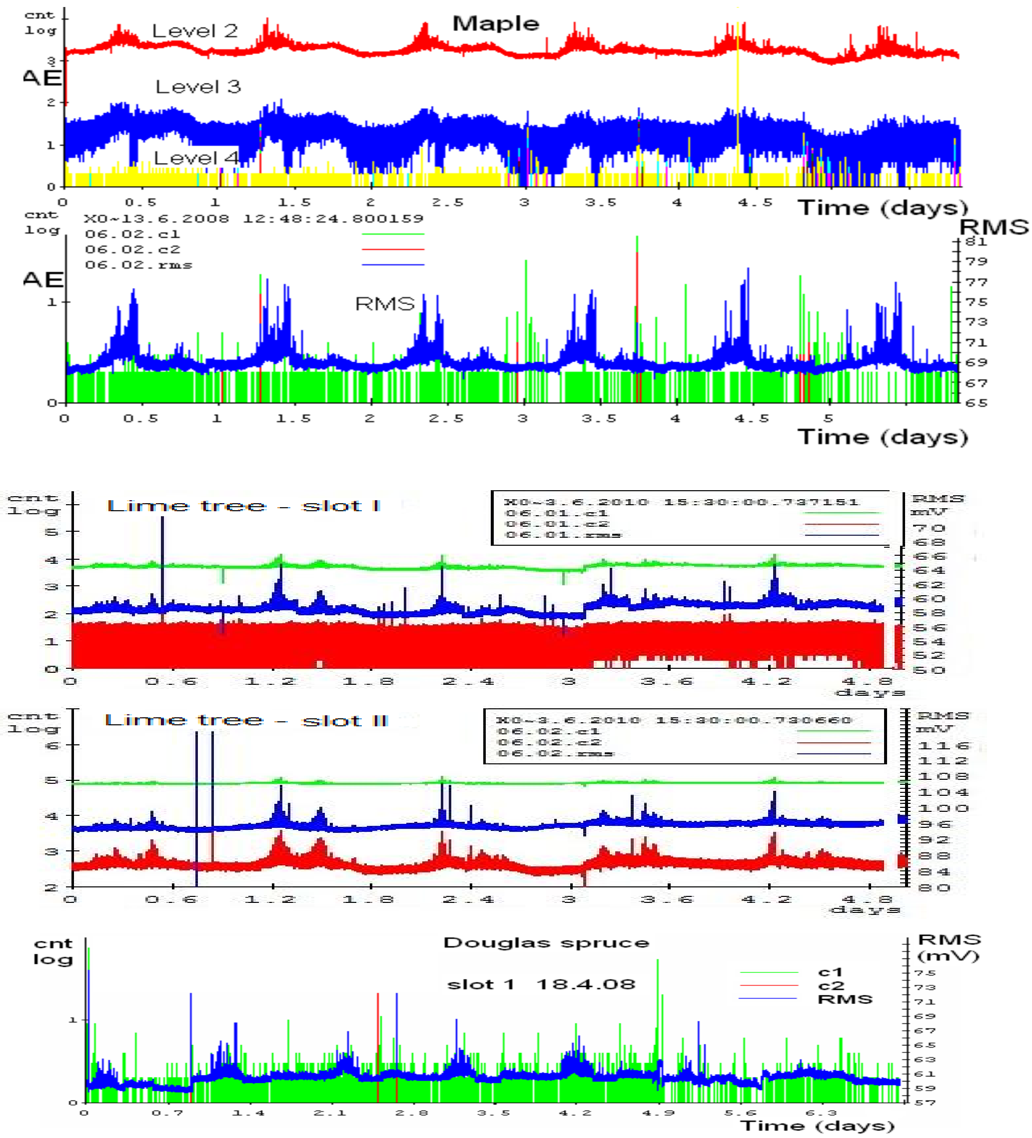
which may be described as an energy-storage-model. Without influence of external forces the system “bubble layer/water column” shifts due to an exchange of internal energy into the minimum of free energy (Laschimke *et al.*, 2004).

MATERIAL AND METHODS

Tests Methodology

We applied the acoustic emission (AE) method to evaluate acoustic responses of diurnal changes of sap flow rate in Maple tree (*Acer pseudoplatanus),* Lime tree (*Tilia cordata)* and Douglas spruce *(Pseudotsuga menziesii).* Sap flow rate was measured at breast height by the trunk heat balance method.

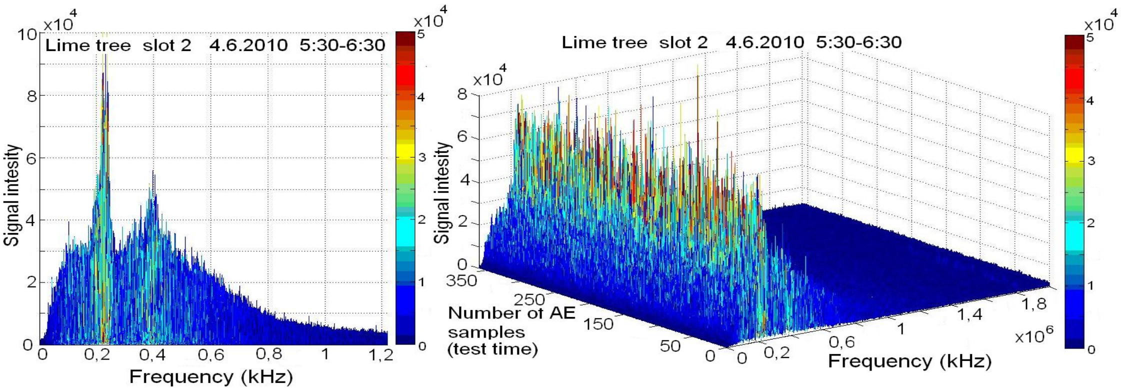
Four and two-channel AE systems Dakel Xedo© were used for presented experiments. Measuring channel units of these equipments were, for the purposes of measuring of acoustic emission parameters, fitted with piezoceramic sensors of type MTR-15 and magnetic MDK-13, the signal of which was, after boosting in preamplifier, sent into analyser and processed by PC. The information from data files was subsequently processed by software DaeShow©, which enables all basic procedures of evaluation – ring down counts, AE burst rate, summation of AE counts, RMS etc. The possibility to divide measured signals into up to 16 pre-adjustable levels (with independent detection thresholds) provides very useful results. Sensors MTR-15 were fixed on steel blade and magnetic sensors MDK-13AS were mounted on the end of



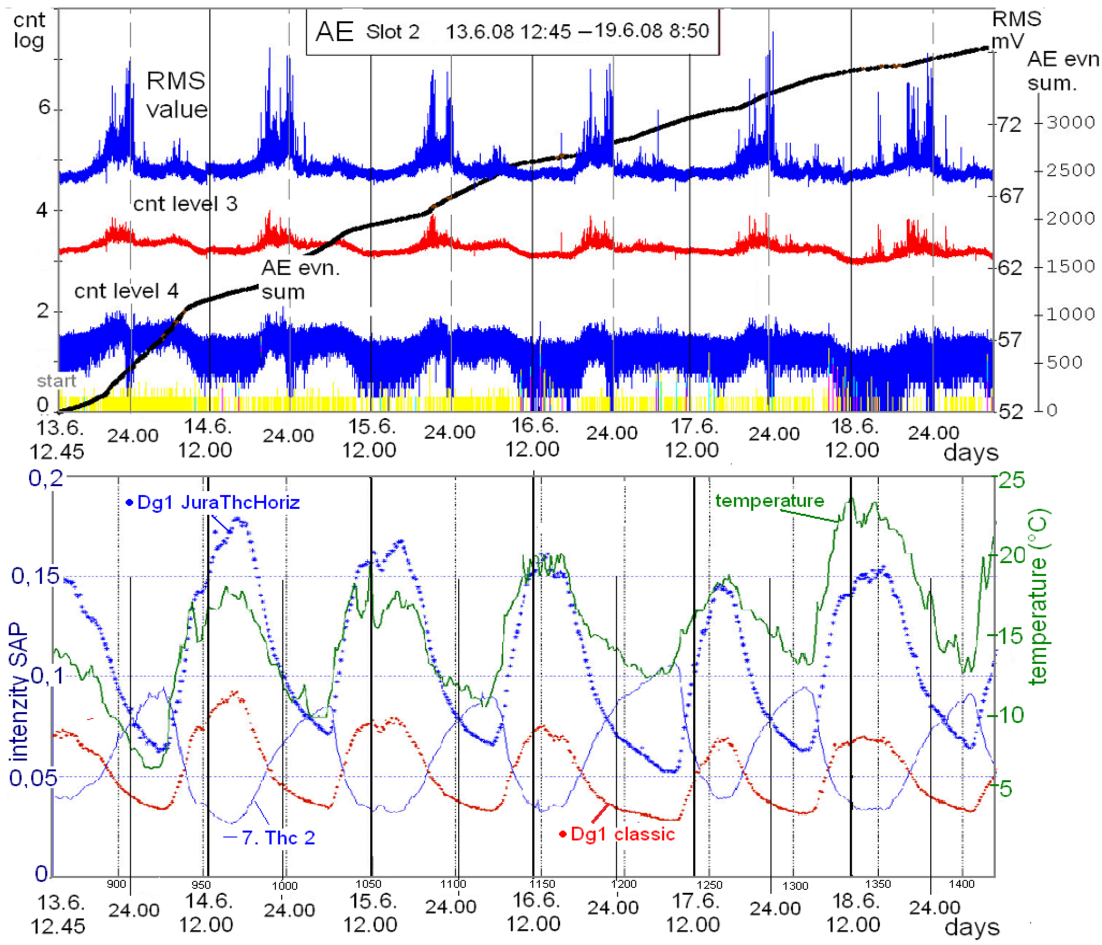
3: *Examples of typical AE records during several days’ measurements: Maple tree – on top (levels 2, 3 and 4 from 16), Lime tree and Douglas spruce – below (2 levels analyzers)*
Source: Authors

cylindric waveguides with conical end (see Fig. 2). The sensitivity of both experimental compositions was compared and conical wave-conductive sensors appeared to be better than blade-form ones. The most active of the applied acoustic levels were those of lower sensitivity (giving lower number of count events).

The Laboratory of acoustic emission of Brno University of Technology is mainly concerned with research of AE method application for diagnostics of cyclically loaded machine parts. The aim of these common measurements was to find the optimal methodology for measurement of AE signal from real trees and to try to find some correlations



4: *Example of evaluation of AE signal in frequency domain*
Source: Authors



5: *Comparison of acoustic emission activity – RMS, selected count levels and summation of all measured AE events (upper plot) with sap flow rate standard parameters (bottom plot) – maple tree* between acquired data of acoustic emission and processes in tested plants. The experiments were implemented at the research base of Mendel University in Brno.

RESULTS AND DISCUSSION

Selected examples of results from tested trees (Maple tree, Lime tree and Pine spruce) are presented in Figure 3. Simplest records of AE activity changes in several days are presented there. AE counts – Number of times AE signal exceeds preset threshold level during any selected portion of a test (see Fig. 1). Our analyzers could record 2 or up to 16 levels (Counts) of AE signal. In figure 3 are plotted three selected energetic levels (from 16) – upper plot and RMS values of the AE signal (Rectified time-averaged AE signal with two levels measurement, measured on linear scale and reported in volts - root mean square (RMS) voltage – for more info see standard EN 1330-9).

The change of acoustic emission activity roughly corresponds to the day cycles. It is evident that the AE signal is more active in the early-evening and partially in the early morning periods.

For evaluation of AE signal sources it will be necessary to use more detailed analysis of the captured signal. It is possible to evaluate changes of rise-time, duration of AE events, peak amplitude etc. Example of evaluation in frequency domain is presented in Figure 4. This could provide another view to estimate the sources of AE signal and this will be the subject of next analysis.

The Figure 5 shows the detailed comparison of current measurement of sap flow rate (measured at breast height by the trunk heat balance method) with basic measurement of acoustic emission activity. The test plotted on Fig. 5 starts at 12.45 hours. The tree gradually runs down the stocks of the night and morning adding moisture in increasing evaporation. The horizontal thermocouple in the measurement of the difference shows an increase in the flow in capillary tubes of xylem (line -7.Thc2). The growth of the transpiration stream should be the reason of the first peak on curves RMS value and AE event sum of AE signal (Figure on top). The tree dimensional dilatation to fill the capillaries (2nd maximum in curves II and III of AE signal) in the afternoon. After reaching the maximum of inventory moisture (early morning) is a large part of the capillary flow aborted. This corresponds to the minimum on the curve -7.Thc 2 and the increased activity of the RMS and Counts.

SUMMARY

Records of RMS value and individual events in the frequency analysis in measurements of acoustic emission (AE) have different activities (maximum of records) at regular intervals depending on the natural processes occurring during daily biorhythm of hydration of xylem vessels.

A correspondence can be found between the records of all the curves obtained from available measurements of temperature fields. Development of acoustic response activities can be found in the areas of increased temperature of differential thermocouple with inverted value (-7.Thc2), which follows its heating and cooling due to sap flow.

The second important activity occurs at the minimum of the curves *Dg 1 classic* and *Dg1 JuraThcHoriz* at the differential records both in the vertical and horizontal layout. Minima correspond to the value (power, size) of the transpiratory current, respectively to dimensional changes of status (change in diameter) in the aboveground part of the trunk. Detailed description of the records (particularly the double peak) in RMS value as well as the increase of AE in the moment of minima on the curves Dg1 classic and Dg1 JuraThcHoriz are now being investigated.

Interesting information can be expected from a detailed frequency analysis of AE events in selected time intervals. Simultaneously a development in the area of acoustic wave conduction by changing the shape of the waveguides is taking place. The specific shape of the waveguides affects the signal intensity obtained.

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