Correlation of Sap Flow Changes in Trees with Signal of Acoustic Emission during Field Measurements

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Abstract
The paper deals with measurement techniques of water conducting system in the trees. In this study we 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. The acoustic emission (AE) method using a series of 16 acoustic levels (in the range of about 0 to 2400 mV expressed in dB) was applied to evaluate acoustic responses of diurnal changes of sap flow rate in maple, pine, ash and lime trees. Sap flow rate was measured at breast height by the trunk heat balance method. The experiments were implemented at the research base of Mendel University in Brno. All the measurements indicated certain periodical changes in AE signal intensity (i.e., dynamical pulses in the studied material, which releases waves recorded by the piezoelectric sensors). These AE records confirm that they reflect embolic events in vessels occurring during more rapid changes in sap flow rate. The AE method is suitable in the more complex studies of sap flow rate.

Keywords: SAP flow, tree, acoustic emission, sensor, waveguide

1. Introduction
Water conducting system of trees (including xylem and phloem) indicates its importance for related physiological processes. However there are still problems how to measure its functioning (which variables and how), especially in the open fields (forests and orchards). 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. Also sap flow is a suitable variable, because it links roots and crowns and provide information about transporting the largest amounts of mass in plant kingdom, which can be decisive for their behavior. Following pioneering work in the last century [1] (Huber 1932), many types of sap flow measurement methods based on a variety of principles (thermodynamic, electric, magneto-hydrodynamic, nuclear magnetic resonance, etc.) have been described. However, only a few of these, particularly those based on thermodynamics, have been widely used in field-grown trees. For example the heat pulse velocity system developed by Cohen et al. [2]. The simple heat-dissipation method is used widely [3]. Direct electric heating and internal sensing of temperature was applied in the trunk heat balance method [4, 5, 6, 7, 8]. The heat field deformation method is based on measurement of the deformation of the heat field around a needle-like linear heater [7, 9, and 10].

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 [11]. Nevertheless there exist also other physical variables carrying important information, which can be measured using different principles. This includes, e.g. acoustic emission method, which can detect quantitative variation of pulses occurring during cavitations events, associated with interruptions of water columns in vessels. However this must not necessarily be a single source of acoustic emissions.

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 [12]. Introduction of ultrasonic acoustic emission into the investigation of plants (begin of eighties) meant significant pro-
gress in identifying sources of AE [13]. 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 by Laschinke at 2004 [14]. 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, 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.

2. Experimental procedure and materials

2.1 Workplaces

The Laboratory of Acoustic Emission of Brno University of Technology is mainly concerned with research of AE method application for diagnostics of damage of cyclically loaded machine parts – axial and radial bearings and gears. Second main area of interest is the detailed observation of fatigue properties of structural materials. The aim of presented common measurements with our colleagues from Mendel University in Brno was to find the optimal methodology for measurement of AE signal from real trees and to try to find some correlations between acquired data of acoustic emission and processes in tested trees.

2.2 Instrumentation and Materials

The acoustic emission method was applied to evaluate acoustic responses of diurnal changes of sap flow rate in ash tree (Fraxinus), black pine (Pinus nigra), maple tree (Acer pseudoplatanus), lime tree (Tilia cordata) and Douglas spruce (Pseudotsuga menziesii) [15, 16]. Sap flow rates were measured at breast heights by the trunk heat balance method in some cases.

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 were mounted on the end of cylindrical waveguides with conical end (see Fig. 1).

Conical wave-conductive sensors appeared to give better results than blade-form ones. In experiments, which were realized in the year 2012, already were used only tests with the waveguides of conical type. The actual test configuration and the real situation in forest are presented on Fig. 2. The experiments were implemented at the forest research base of Mendel University in Brno.
3. Overview of results

Examples of basic results from tested trees are presented in Figs. 3 and 4. Simplest records of AE activity changes in several days are presented; AE counts and root mean square (RMS) voltage of the AE signal. In Fig. 3 there are up-to-date records, gained at simultaneous observation of pine and ash trees for a period of two weeks. From the record in Fig. 3, it is evident that the activity of the AE signal shows not only the daily changes over time, but also in the connection with the actual weather - the first, second, fifth and sixth days were relatively cold and rainy weather. Other days, it was partly cloudy to sunny. At the same time, it is clear that the changes of the pine were more considerable than the activity of ash tree (the measuring chain settings were identical). The maximum activity of the AE signal was observed in the early afternoon in this measurement.

Our measurement could record up to 16 levels (Counts) of AE signal. In Fig. 4 there are plotted only selected energetic levels and RMS value of the AE signal. The change of acoustic emission activity on maple roughly corresponds to the day cycles. It is evident that in this
case the AE signal is more active in the early-evening and partially in the early morning periods.

Figure 3 Comparison of the two weeks parallel measurements of the AE signal on pine and ash trees (June 04 – 18, 2012)

For evaluation of AE signal sources it is 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. Some examples of evaluation AE counts in frequency domain are presented in Figures 5, 6 and 7. This could provide another view to estimate the sources of AE signal.

Figure 4 Examples of typical periodical changes of AE records during a six days measurement (maple) [15]

Figure 5 is a comparison of frequency characteristics of AE signal events on the pine tree in measurements at the different weather (cloudy vs. sunny). On the left there is a record in a 3D presentation with the timeline. In figure 5(b) there are the same records in a 2D presentation. A similar comparison of frequency spectrum of AE events is on figure 6. Records in Figures 5 and 6 are from the same time period. For comparison is given similar recording obtained previously in the monitoring of the lime tree. Of all the records are obvious changes in the spectrum of events at different times and for different trees.
Fig. 8 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 measurement starts around midday. 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. The 2 and the increased activity of the RMS and Counts.

A correspondence can be found in this case 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 (Fig. 8).

The second important activity occurs at the minimum of the curves Dg1 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 is now being investigated.

Figure 8. 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 [16]
4. Conclusions

Presented application of acoustic emission method for monitoring of changes to the SAP flow showed significant changes of selected parameters of the signal in different daily hours on all monitored trees (maple tree, lime tree, ash tree, pine and Douglas spruce). The regularity of these changes and a comparison of changes of AE signal parameters with results of the other standard methods suggest that they correspond to the daily life cycle of the trees. The latest long-term records also confirmed the connection of changes to the life cycles of trees (as a result also the AE signal changes) with the weather, humidity, temperature, sunlight, etc.

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.

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.

Application of acoustic emission method for evaluation of growth parameters of the trees can significantly extend the knowledge of the nutritional status of trees and the status of forest stands in the future. Identification of the precise resources AE signal, of course, requires further detailed studies.

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