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THE ACOUSTIC EMISSION IN THE NEST OF THE HONEY BEE DEPENDING ON THE EXTREME WEATHER CONDITIONS

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Abstract

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The vibroacoustic signals are an important part of communication in the honey bees (*Apis mellifera* L.). The aim of this study was to observe the acoustic emission that varies in a bee colony during different weather phenomena (strong winds and hailstorms) and to estimate the nature and the extent of the reactions of the colony by the analysis of the obtained data. Experiments were carried out in the volume-reduced hives. The specific weather phenomena were followed by significant ($P < 0.0001$) increasing of the intensity of the acoustic emission in the colony in comparison with acoustic emission before or after the phenomena. Close linear positive relationship was confirmed between the intensity of wind gusts and intensity of acoustic emission ($r = 0.72$; $P < 0.001$). With the increase in the maximum gust of 1 $\text{km}\cdot\text{h}^{-1}$, the intensity of acoustic emission increased by 0.1466 mV. The character and degree of reaction of the colony can be estimated with analysis of the measured data. Permeability of vibration signals directly induced weather phenomena through the construction of the experimental hive and the stress in the colony are discussed. Observation of the acoustic emission distributed within the colony is one of the methodical alternatives for research of the vibroacoustic communication in the colony.

Keywords: vibration, acoustic emission, honey bee, *Apis mellifera*, response

INTRODUCTION

Use of non-destructive test method – the acoustic emission (hereinafter referred to as AE) serves not only for testing inanimate material where this very sensitive verification serves e.g. when detecting deformations, initiation of micro cracks or location of defect or corrosion damage in a phase prior to occurrence of the actual process itself. Currently it has been extended to include also applications in the biological field (e.g. termites, bark beetles, house longhorn beetle larvae, etc.). (FUCHIKAWA *et al.*, 2012; VARNER and VARNER, 2012). It has been used to understand activity, the very nature, and both external and internal manifestations of the selected biological species.

AE is a non-destructive testing technique. In contrast to other non-destructive techniques it is passive inspection method which can verify the entire volume structure of construction. The advantage of the acoustic emission in comparison with other diagnostic methods is the continuous monitoring of objects, detection of internal changes before the actual event, and time savings compared to gradual testing by other methods. The acoustic emission method detects only active defects. The emission of acoustic pulses occurs in the source of acoustic emission during release of energy due to occurrence of internal or external stress (KREIDL and ŠMÍD, 2006) (PAZDERA *et al.*, 2004).

The acoustic emission (AE) method detects and characterizes the process development. It works with the aim of an "interception" of acoustic activity which is emitted by processes occurring in the material (plastic deformations, initiation and development of failure, tightening and widening of cracks, leakage of a medium through continuous crack), etc. The AE method detects/locates and evaluates the activities and defects disturbance right and just in their course and it can be described as passive (KOPEC, 2008).

Acoustic emissions are the stress waves produced by the sudden internal stress redistribution of the materials caused by the changes in the internal structure. Possible causes of the internal-structure changes are crack initiation and growth, crack opening and closure, dislocation movement, twinning, and phase transformation in monolithic materials and fiber breakage and fiber-matrix debonding in composites. Most of the sources of AEs are damage-related; thus, the detection and monitoring of these emissions are commonly used to predict material failure. In technical diagnostics, AE method has been used to monitor rotational part status (friction and cavitation of bearings/gears), detection of micro-cracks, pressure vessel defects, tubing system defects, aircraft structure evaluation/testing, and bridge status diagnostics. Major advantages of AE include continuous monitoring of the object, time savings, and forecast abilities of the concept. On the other hand, AE wave source is not always obvious, as the emitted energy may result from several phenomena inside of the part. Further variable factors include shape of the object, surface area, material structure, and homogeneity level (KREIDL, ŠMÍD, 2006).

The bees emit an abundant spectrum of sounds (WENNER, 1964; DIETLEIN, 1985; KIRCHNER, 1993; JESKOV, 1995). Vibrations and sounds, collectively called vibroacoustics, play significant roles in intracolony communication in social bees. Substrate vibrations predominate as vibroacoustic modalities, with only honey bees having been shown to be able to hear airborne sound (HUNT and RICHARD, 2013). The typical auditory organ, such as ear in the case of humans, does not appear on bees. Besides, the evidence of their perception of sounds transmitted by air, was very sketchy or none until recently (DRELLER and KIRCHNER, 1995). The Johnston's organ and subgenual organ are the primary receptors for vibroacoustic signals. Located within the pedicel of the antenna, the Johnston's organ is connected at its distal end to a ring of pits in the articular membrane between the pedicel and first segment of the flagellum. Movement of the antennal flagellum inresponse to vibrations and sounds (in honey bees) is sensed by the Johnston's organ and translated into nerve impulses that are transmitted to the central nervous system. Subgenual organs are located in the proximal portion of the tibia on all legs. Substrate vibrations received via the legs are sensed by the subgenual organs where they are translated into nerve impulses that are transmitted to the central nervous system (HUNT and RICHARD, 2013).

The bees are able to sense the vibrations in materials very sensitively though. Significant sound signals during the waggle dance prove that except the dance figures the vibrations are also important. These air born vibrations are emitted by the bees using the chest muscles in the rank of 200–300 Hz with the amplification up to +12, 4 dB (NIEH and TAUTZ, 2000). These vibrations are extremely important during the communication of the bees with the goal of getting information about the source of nourishment (SANDEMAN *et al.*, 1996; TAUTZ, 1996; TAUTZ and ROHRSEIT, 1998). Sounds during the communication of the bees are much more important, than it was presumed until now (DRELLER and KIRCHNER, 1995).

The goal of this experiment was observation of the acoustic emission in the colony depending on extreme weather conditions (hailstorms, strong winds) and estimating the nature and extent of reactions of the colony by the analysis of the data.

MATERIALS AND METHODS

- The entire mating box includes the following parts:
- Cover – requires sufficient thermal insulation.
- Shallow extension – dimensions 37 × 15 which is placed at the experiment habitat. It is possible to insert up to 5 frames into the entire space of super.
- Bottom board – has a low opening height, i.e. height of the bottom board, clearance respectively; between the bottom board and the bottom edge of the frames is 3 cm or less.
- On the front bottom edge of the bottom board there is apparent area overlapping outside the boundaries of the hive ground plan. The area is called fly-in edge. It facilitates "take off" and "landing" of the bees. Over the entire width of fly-in edge, front wall of the bottom board respectively, there is a slot. It is called entrance board; bee "main entrance" to the hive. Depending on the position of frames relative to entrance board we distinguish longitudinal setting (cold way) and transversal setting (warm way). In the experiment frames have been set in the cold way.

For the pilot measurement, a small-size beehive was chosen (designation Q05/13). The hive contained five frames with dimensions of 37 × 15 cm. Two identical sensors (designated Slot01 and Slot02, manufactured by Dakel Company) were placed in the hive: Slot01 and Slot02. This naming scheme corresponds to individual channels (slots) of the Dakel XEDO analyzer.

The Slot01 sensor was placed on a sheet metal plate with dimensions of 3 × 10 cm. The sensor was coupled with a 35 dB preamplifier. Contact area was treated with acoustic paste for improved acoustic coupling. The actual sensor was fixed in place using a rubber band and the entire plate was hung into the

1: *Row of small hives used in the experiment. Photo by authors.*

2: *Slot01-02 sensors on the sheet metal plate in the hive interior. Photo by authors.*

hive between the frames. To have enough space, one frame was necessary to be removed from the hive. The plate was specially chosen for the environs of the hive which is highly corrosively aggressive. The sheet metal plate had specific dimensions because of the dimensions of the hive but also for the reason of the size of the carrying medium for the acoustic signal transmission. The sensor in the contact area with the lead plate was treated with coupling medium for balancing unevenness and improved signal transmission. This coupling medium consists mainly of bee wax which was chosen for hygienic reasons (TLAČBABA, J., ČERNÝ, M., PŘIDAL, A., DOSTÁL, P.).

A sensor was placed on a metal plate which was inserted to the nest frame. The location of the sensor was between the nest frames in the front part of the nest grouping in the space of the nuc and thus closer to the circular mening that functions as an entrance for the bees into the space of the hive. This sensor was struck the most during the wind gusts in the measured sample.

Considering the technical possibilities of the acoustic emission XEDO-Dakel device used in the workplace in MENDELU, the AE parameters such us counts over two selected limits, power density (sometimes also as an effective value of power) RMS, which is advantageous when taking into account the capacity of the saved data (max. several GB/24 hours from one channel). The effective value is often labeled with the index RMS from the English term „Root Mean Square“. In the case of the acoustic emission is valued the mean effective value of the detected signal – RMS.

The signals RMS from both sensors were pre-amplified and later processed by the Dakel XEDO AE analyzer. An Ethernet-connected laptop PC with Dakel DaeMon software was used for continuous viewing and storage of the AE data. The data from AE monitoring has been evaluated using Dakel DaeShow software to provide visual representation and statistics.

Phenomenon No. 1

The phenomenon 1 was monitored in the experiment during which solid downfalls in the form of hailstones were subjectively observed in the institutional apiary. Phenomenon 1 starts on 10th June 2013 at 15.00:00 hour and terminates on the same day at 16.00:00 hour. This interval is depicted as a red abscissa in Fig. 3.

The record on the hanging steel board contained only the activity of the colony in the nuc. This fact must be verified by another laboratory experiment, in which the nuc was exposed to the stimulated impact of falling hail stones. The nuc was without bees and it was equipped with the same amount of frames with the bee's creation and sensors that were applied by the identical way just as during the subsequent observation of the weather conditions. The apparatus was displayed to the following configuration of unit:

- Amplification g = 45 (dB);
- Maximum extent of the measurements adc = = 2 000 [mV];
- Count limit c1 = 604 [mV], c2 = 1 200 [mV];
- es = 1 200 [mV], ee = 1 200 [mV], dead time dt = 992 [us];
- Oscilloscope trg = 1 200 [mV], memory sm = = 10 000 [words], pretrigger pt 1 000[words];
- Oscilloscope perioda pr = 1 000 [ms], timeout to = = 5 000 [ms], sampling rt = 2 [MHz];
- Trigger source = (TRG_TRIGGER), master tm = ();
- interval count ic = 1000 [ms].

During the impact of the material on the metal roof of nuc was proved that the impact of hail sones did not affect the sensors in the exposed nuc. This proved that all recordings of RMS signal were made only from the aggravation of the colony in the sample. There were made hail stones of a circular shape and mass about 11 grams for the simulation, these hail stones were gradually dropped by hand onto the roof of the nuc. The impact of hail stones hitting the roof did not affect the recordings of the sensor and spreading of the acoustic emission through all construction components of the nuc was not proved. That is why measuring the acoustic emission during the different weather occurrences reflect only acoustic emission provoked by the bee's activity.

Phenomenon No. 2

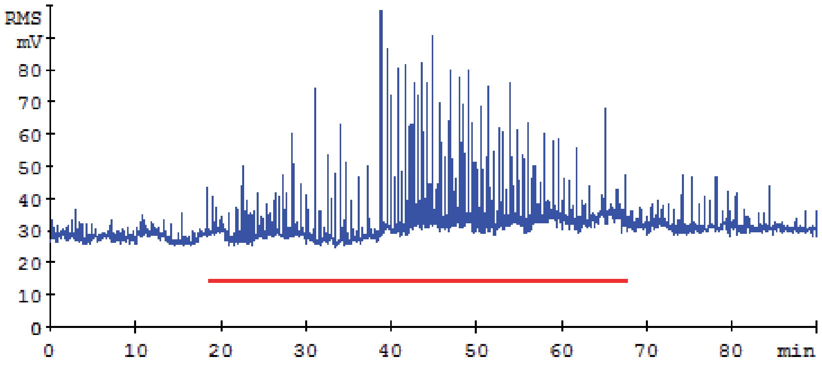
The second phenomenon took place during deteriorated atmospheric conditions on 4th August 2013 at 19.30:00–22.30:00 hour, when this locality was under the strengthened thrusts of wind, in the institutional apiary where a measuring device was placed in order to observe the acoustic emission in dependence on the wind. The RMS data were analysed from the acoustic emission and both average and maximum thrusts of the wind. A meteo station WH1090 was used and it measured the velocity of the wind: 0 to 45 $m \cdot s^{-1}$, the interval of intrinsic values and the transmition of the data: 48 seconds and the transmission frequency: 868 MHz. The recorded information from the meteo station and the measuring equipment was saved in 5 minute intervals during which the arithmetic mean of the set of values in the measuring interval was applied. The station recorded the average wind and maximum thrusts of the wind in the station. Arithmetic means in the interval in compliance with the independent variable were calculated for the regression analysis from the standard first interval. Two sensors that recorded the activity of the bee colony were placed in the nuc. Sensor number 1 was situated closer to the hive entrance and the second sensor was placed in the rear part of the nuc.

Statistical evaluation

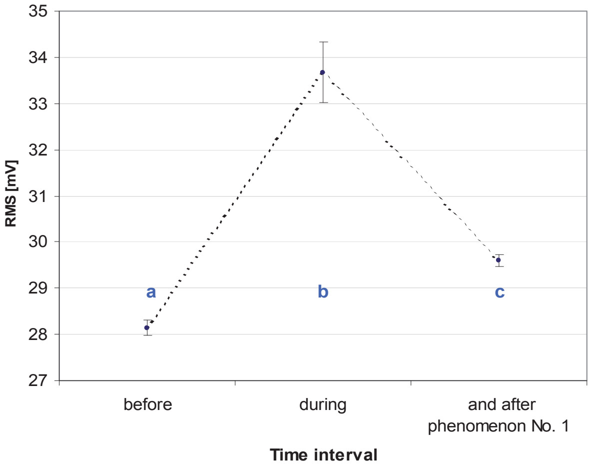
Statistical evaluation of the data was carried out with the use of the statistical software Microsoft Excel 2000 series. The connections between the intensity of the RMS signal and the intensity of the wind were calculated by the Pearson correlation and linear regression analysis. The differences in the intensity of the RMS signal were evaluated by using an analysis of variation (ANOVA) with a subsequent testing with the help of the confidence interval. The intensity of the RMS signal was assessed with the arithmetic mean and with the minimum and maximum value. The values of the RMS signal were averaged in the intervals of 5 minutes and the same was done with the average intensity of the wind. The maximum wind thrusts were registered in the interval of 5 minutes at the time from 19:30 to 22:35 o'clock.

RESULTS

The intensity of the RMS signal measured prior, during and after the phenomenon No. 1 is depicted in Fig. 3. In the whole time interval of the duration of the phenomenon No. 1 (see the red line segment) was discovered provably increased intensity of the RMS signal ($P < 0.001$) in comparison to the duration of the intensity of the RMS signal prior and after the phenomenon No. 1 (Fig. 3). The intensity of the RMS signal after the termination of the phenomenon was provably higher in comparison to the conditions prior the phenomenon No. 1, in the average about 1,448 mV (Tab. I). At the same time, it was significantly provably lower on the average when compared to the conditions during the phenomenon No. 2 (Fig. 3) and the same applies to the average about the maximum values (Tab. I). The differences in the minimum values of the RMS signal are negligible (Tab. I). Standard symbols in statistics, when P = probability and n = number of the elements that are important to determine the degrees of the latitude.



3: *RMS signal around phenomenon No 1 (red abscissa indicates time interval with the incidence of hailstones)*

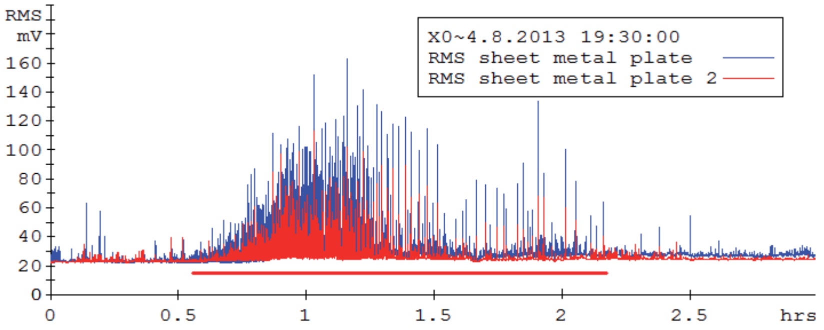


4: *Intensity of RMS signals before, during and after phenomenon No. 1 (average ± confidence interval P < 0,0001; different letters for significant differences P < 0,001; n = 1801)*

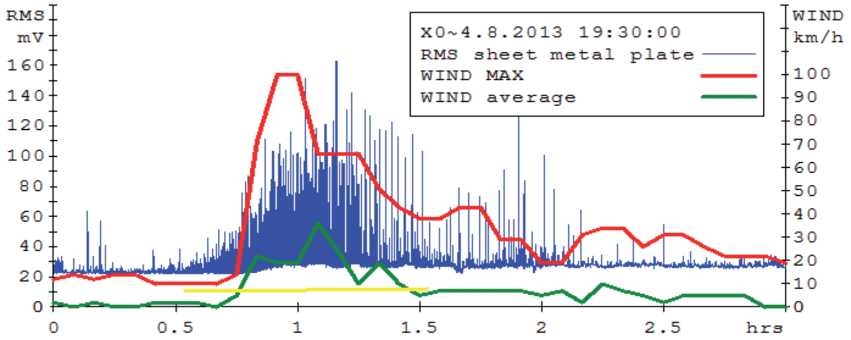
I: *Average, minimum and maximum values RMS signals [mV] around phenomenon No. 1*

	Before	During	After
Average	28,141	33,672	29,588
Min.	24,447	28,121	26,221
Max.	56,243	90,381	37,639

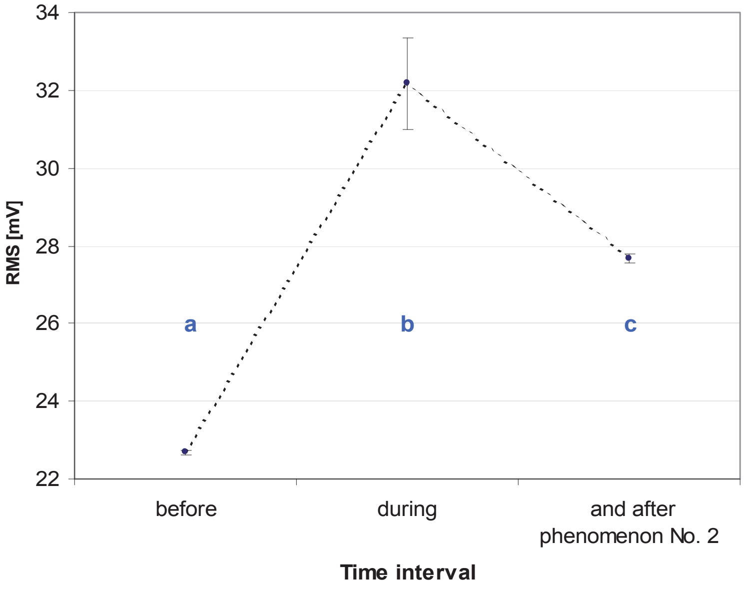
The intensity of the RMS signal measured prior, during and after the occurrence of the phenomenon No. 2 is portrayed in Fig. 5. The blue color represents the measurement progress with the sensor No. 1 and the red color depicts the development of the measurements of the sensor No. 2. During the whole time interval of the duration of the phenomenon No. 2 (Fig. 5; red line segment) was discovered an



5: *RMS signal around phenomenon No. 2 (red abscissa indicates time interval with the incidence of phenomenon)*



6: *RMS, average wind speed and maximal blast (mV, km/h) around phenomenon 2 (yellow abscissa indicates time interval with the incidence of phenomenon)*



7: *Intensity of RMS signals before, during and after phenomenon No. 2 (average ± confidence interval P < 0.0001; different letters for significant differences P < 0,001;* $n_x = 3601$*)*

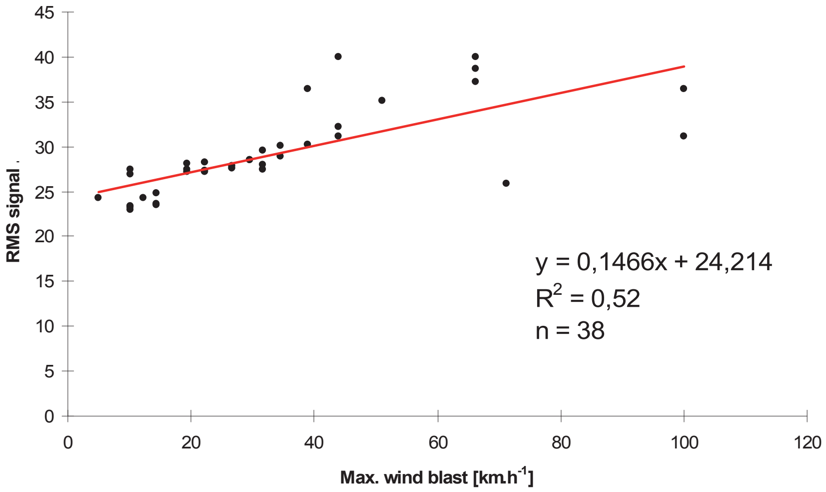
II: *Average, minimum and maximum values RMS signals around phenomenon No. 2*

	Before	During	After
Average	22,683	32,175	27,660
Min.	21,970	21,767	25,053
Max.	37,259	163,243	54,322

increased intensity of the RMS signal with both sensors in comparison with the progress of the intensity of the RMS signal prior and after the phenomenon No. 2. The values obtained by the sensor No. 1 (situated closer to the circular hole, Fig. 4) were provably higher (P < 0.0001) than the ones gained by the sensor No. 2 (situated further away from the hole).

The records of the RMS signal by the sensor No. 1 (blue curve), maximum wind gusts (red curve) and the average velocity of the wind (green curve) during the phenomenon No. 2 are displayed in Fig. 6. In the whole time interval of the phenomenon No. 2 (see the yellow line segment) was also discovered a provably increased intensity of the RMS signal (P < 0.001) in comparison to the progress of the intensity of the RMS signal prior and after the phenomenon No. 2 (Fig. 5). The intensity of the RMS signal after the terminative of the phenomenon was provably higher (P < 0.0001) when compared to the conditions prior the phenomenon No. 2, with the average about 4, 977 mV (Tab. II). At the same time, on the average it was significantly lower compared to the previous state during the phenomenon No. 2 (Fig. 7) and the same is true about the maximum values (Tab. II). The differences in the minimum values of the RMS signal are insignificant (Tab. II).

From the developments of the RMS signal and the wind velocity is clearly evident, that their increases and decreases mostly correspond to each other in terms of time (Fig. 6). Between the intensity of the RMS signal and the maximum wind gust [1] or the average wind velocity [2] was discovered a very likely



8: *Regression analysis of the maximum wind gust and of the intensity of the RMS signal*

reliance expressed by the correlation coefficient ($r_1 = 0.72$ a $P < 0.001$ a $r_2 = 0.74$ a $P < 0.001$).

The regression analysis for the maximum wind gusts and a corresponding intensity RMS in terms of time confirmed the positive linear dependency with the moderately substantial determination coefficient $R^2 = 0.52$ Fig. 8. It is inferred from the regressive coefficient that when the maximum wind gust is increased about 1 km·h^{-1}, the answer on the sensor measuring the acoustic emission has the intensity of the signal increased by 0.1466 mV.

The measurement during the phenomenon No. 1 and 2 are similar to each other with the increase of the RMS signal (Fig. 3 a 5). The character of their increase and decrease of the RMS signal is evident from their developments. The levels of their average and maximum RMS signals vary (Tab. I and II).

DISCUSSION

It is evident from the obtained measurements, that during the measuring of the acoustic emission inside of a honey bee nest in a wooden hive decreased in size, can be watched the reactions of the bees which were provoked by extreme weather conditions. The reaction of the bee colony was observed only during deteriorated weather conditions that caused some activities in the measuring sensor. The sensors were insulated from the direct impacts of extreme weather, as explained in methodology, and the measurements were not distorted by other factors.

The impacts of the hail stones were not a part of the records of the measured acoustic emission, because the quakes provoked by the hailstone impacts on the metal roof could not be probably transmitted by material, when there were differently material-based layers between the sensor and the metal roof (3 mm of steel lid, 50 mm of polystyrene, 1 mm of hardened foil, 10 mm of wooden frames made of soft wood, wax in the form of the bee creation and an air gap). The reduction of transmission of the signal through composite materials was proved by HAMSTAD (1986) in the study at composite materials, where the transmission velocity and permeability of signal AE was dependent on the composite properties.

Honey bee during recruitment or communication with the other individuals in the hive uses the bee waggles, when the vibrating body transmits information for other bee workers that register the flow of the sound that is transmitted in their closest proximity (MICHELSEN *et al.*, 1986; DRELLER and KIRCHNER, 1993; MICHELSEN, 2003; HRNCIR *et al.*, 2006). Waggle dance during the transmission of the vibrations from the pectoral muscles on the basis (TAUTZ *et al.*, 1996), with maximum signal transfer when the thorax is fully laterally displaced during a waggle (STORM, 1998; HRNCIR *et al.*, 2006). The various positions of the legs are so that they could perceive both horizontal and vertical parts of the bee vibrations. (SANDEMAN and *et al.*, 1996; ROHRSEITZ and KILPINEN, 1997), and the vibrations are interpreted into nerve impulses through the subgenual organ (KILPINEN and STORM, 1997). This entire apparatus works well for accepting vibrations that are transmitted in the space inside the hive.

Even though substrate vibrations during waggle dancing transmit information from the dancing bee to bees attending the dance, the substrate vibrations may not provide specific information about the velocity and direction of the dancer during the waggle run (NIEH and TAUTZ, 2000).

The presence of very sensitive vibration receptors in insect legs has long been known (AUTRUM, 1941; AUTRUM and SCHNEIDER, 1948; SHAW, 1994), and the morphology of one of these receptors in bees, the subgenual organ, has been described (SCHON, 1911; MCINDOO, 1922). The mechanical behavior of the bee subgenual organ to vibrations applied to the leg show it to be maximally displaced, and so presumably most sensitive, to frequencies between 300 and 600 Hz (KILPINEN, 1995; ROHRSEITZ and KILPINEN, 1996).

It is apparent from the measurements that the impact of the strong gusts of wind aggravated the bees that were closer to the circular whole more than the ones that were further away from it. This might be also related to the sudden and collective returns of the bee (right before and for the duration of the phenomenon 2. We can completely exclude any kind of an impact of the wind itself coming into the circular hole among the bees because the measured energy of the signal corresponds with the vibrations that are caused by the limbs of the bees and not the impact of the wind directly on the sensor that was fixated by the bee's creation. The sensor in the middle of the hive (i.e. further from the circular hole) probably reflects more the extent of the overall reaction of the bee colony, that it was provoked by the extreme situation No. 2.

The RMS signal values most likely reflect the intensity of the manifestation of the bee colony. It is possible to assume that this manifestation provoked by the weather had the characteristics of aggravation or even stressing the bees.

The stress resulting from negative influence of the source of the acoustic emission on the bee colony also presupposed (JIANKE, 1996) on the stations of the bees close to extensive grand works. These grounds works provoked strong soil vibrations that were most likely transmitted on the bee hives. These bee hives shortly after the launching of the ground works succumbed to the calcification of the bee fetus whose symptoms disappeared only shortly after their end. During the repetition of these impulses, the bees are able to suppress the reactions on the impulse (KALA, 2009).

But that is obviously related to the characteristics of this impulse, for example who its intensity and duration. It was not discovered during our observation that the bees would reduce the reaction on the impulse during its action.

The impact of the vibrations on the honey bee can be assumed from the results of studies about bee colonies that were subject to long distance transport (WELCH *et al.*, 2009; AHN *et al.*, 2012). Evoking the stress must by confirmed by other methods (LIN *et al.*, 2004).

The gained results imply that one of other approaches to watching bee breeding is observing acoustic emissions transmitted inside of it. It is necessary to further explore this method as a new direction in the vibroacoustic research that is appealed by HUNT and RICHARD (2013).

SUMMARY

Measuring the acoustic emission in the bee colony during extreme weather conditions (hail storms and strong wind) brought the following discoveries:

- During strong wind gusts and hail storms occurred a provable increase of intensity of the acoustic emission ($P < 0.0001$) in the bee colony in comparison to the intensity of the acoustic emission before and after the termination of the phenomena. The intensity of the acoustic emission after the end of the phenomenon was provably higher ($P < 0.0001$) in comparison to its condition before the phenomenon.
- It was discovered that with the increasing or decreasing intensity of wind gusts, the intensity of acoustic emission keeps linearly changing in the bee hive ($r_1 = 0.72$; $P < 0.001$).
- During increasing the maximum wind about 1 $\text{km}\cdot\text{h}^{-1}$, the intensity of acoustic emission was increased by 0.1466 mV.

It is apparent form the attained results that during extreme weather conditions, the activity of bees was increased, which was obvious by the increase of intensity of the acoustic emission in the bee hive. The nature and reaction of the bees can be estimated by an analysis of the measured data. The method of observing the acoustic emission transmitted inside of the bee hive is one of the next advancements in the vibroacoustic research.

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