PROTOTYPE OF GLASS-ROD WAVEGUIDE FOR MONITORING OF BEER FERMENTATION PROCESS USING ACOUSTIC EMISSION

PROTOTYP SKLENĚNÉHO VLNOVODU PRO MONITOROVÁNÍ PROCESU KVAŠENÍ PIVA MĚŘENÍM AKUSTICKÉ EMISE

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Abstract

The paper presents results of preliminary experiment focused on usage of glass-rod waveguide for acoustic emission (AE) monitoring. AE was previously used to monitor fermentation process in the hopped wort. We learned that it was necessary to develop a more effective way of sensor coupling within the fermentation tank. A glass-rod solution was used for direct contact with the hopped wort and this setup was subject to laboratory testing. The first study compared two AE analyzer slots with different frequency responses. Optimized waveguide design will be used in next phase of fermentation monitoring project.

Key words: beer, fermentation, cylindroconical fermenter, acoustic emission

Abstrakt

Článek popisuje výsledky pilotního experimentu zaměřeného na testování použitelnosti skleněného vlnovodu při měření akustické emise (AE). Na základě výsledků předchozích měření AE bylo nutné vyvinout nový způsob umístění snímačů AE za účelem dosažení lepšího akustického kontaktu s probíhajícím procesem. Jako vhodný materiál byla zvolena skleněná tyč, která bude umístěna do cylindrokonického tanku (CCT) a bude v přímém kontaktu s mladinou. Tyč byla testována v laboratorních podmínkách s dvěma různými sloty analyzátoru AE. Výsledky tohoto experimentu budou využity při výrobě skutečné sestavy vlnovodu pro mikro-pivovar Destila.

Klíčová slova: pivo, kvašení, cylindrokonický tank, akustická emise

Introduction

In 2010, our research team presented results of the first phase of the research project in the Destila micro-brewery. The innovative concept was focused on usage of acoustic emission (AE) method for monitoring of beer fermentation process. However, after series of testing, it became clear that a different approach had to be chosen. In the original setup, AE sensors were found ineffective when placed on several positions on the cylindroconical fermenter (CCT) body. This might have been due to complicated tank structure and used material. In this paper, authors further elaborated the method and presented refined waveguide solution. [3]

Beer Fermentation Basics

Fermentation is the process by which fermentable carbohydrates are converted by yeast into alcohol, carbon dioxide, and numerous other byproducts. It is these byproducts that have a considerable effect on the taste, aroma, and other properties that characterize the style of beer. [1]

Cylindroconical fermenters represent common fermentation systems used today to produce both lagers and ales. As the name implies, the enclosed vessels are vertical cylinders with a conical base and, normally, a dished top. This design allows for easy yeast collection and CIP cleaning. They range in size between 100 and 7,000 hl, have from a 1:5 to a 3:1 ratio of height to diameter, and work under pressures of from 1 to 1.3 bars above atmospheric pressure. In fermentation vessels with a ratio greater than 3:1, there is a tendency for increased production of higher alcohols at the expense of esters. Vessel geometry plays an important role in fermentation. As the height-to-diameter ratio increases, so does the mixing of yeast and wort, as well as the fermentation rate. [1]

Acoustic Emission Method

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 AE 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. AE technique has proven useful in fatigue testing and destruction experiments. 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. [2]

Destila Micro-Brewery

In Mendel University, there is a Destila micro-brewery in the food production laboratory of the Department of Agriculture, Food and Environmental Engineering. The Destila system serves for model and/or analysis purposes. It allows for amount modifications of malt, hops, yeasts, and other ingredients. The temperature can be streamlined within the actual brewing process as well. The variable configuration features make the micro-brewery an ideal ground for various research projects. Figure 1 shows the fermentation section of the micro-brewery.

The Destila micro-brewery consists of the following main components: mash tun, cooling system, open fermentation tank, storage tank, cylindroconical fermenter, filtration/racking tank, and accessory (electric, boiler, cooling system, and filtration).

In this experiment, beer fermentation process in cylindroconical fermenter tank has been subject to AE monitoring. This device allows for combined and streamlined fermentation process as opposed to primary fermentation in open fermentation tank and secondary fermentation in storage tank. The cylindroconical fermenter body is made from Cr/Ni stainless steel.

Figure 1. Cylindroconical fermenter in the Destila micro-brewery. Note the observation opening on top surface. Photo by David Varner.

Glass-rod Waveguide Solution

For current phase of the research, a glass-rod waveguide set was designed. This feature included an entire new tank accessory assembly. There are two openings in the top of the CCT. These serve for observation purposes, as the lids include glass inserts that allow for watching the level and appearance of the hopped wort inside the tank. A small lamp is fixed to one of the openings to make the observations easier. In this research, the original glass in the lid assembly will be replaced with a transparent polyurethane plate with opening in the center. This opening was designed to host the glass-rod waveguide. The 12 mm diameter glass-rod will be fixed in the opening by a flexible glue-like substance that will provide acoustic isolation as well. Figure 2 shows original status of the opening and glass see-through lid.

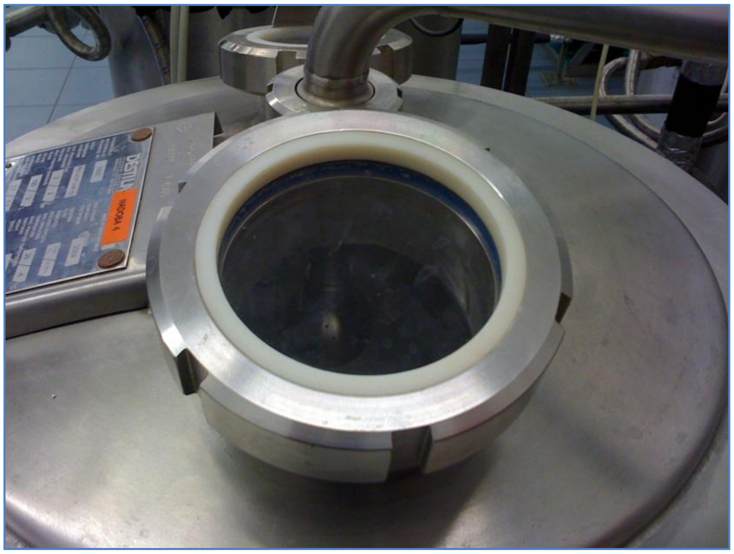

Figure 2. Opening on the tank body with original glass lid. A new glass-rod waveguide assembly will be inserted instead of the glass. Photo by David Varner.

This preliminary study was supposed to address three essential issues:

- Overall ability of the system to capture the AE signal through the glass-rod waveguide
- Selection of AE analyzer slot for optimal AE measurement performance
- Possible influence of different immersion rate of the glass-rod waveguide

While the first two issues were quite straightforward, the third one was closely connected to real life conditions in the beer fermentation tank. During the fermentation, the hopped wort level does not remain the same as the liquid is drained out for beer quality check purposes. Also, the yeast is being removed from the tank to streamline the fermentation process. It is clear that changes in immersed portion of the waveguide might affect the resulting data. Thus, it was crucial to determine whether variations of the immersion zone length were likely to affect the AE data properties.

Experiment Description

In order to properly solve the issues listed above, a simple setup was designed in laboratory conditions. A common 800ml laboratory glass beaker was equipped with a polystyrene lid with two openings, one for a testing glass-rod waveguide (300mm long, 12mm in diameter) and one for the conical water-filler. A single piezoelectric sensor of appropriate size was glued on one end of the glass-rod to capture the waves coming from the beaker along the glass-rod. Then, a common sparkling water was poured through the filler into the beaker to simulate bubble behavior of the hopped wort. During this pouring, AE was monitored. Figure 3 shows glass-rod waveguide with the AE sensor attached to its end.

Figure 3. Test glass-rod waveguide with piezoelectric AE sensor attached. Photo by David Varner.

Figure 4. Testing glass-rod waveguide immersed in the water. Note the blue filler inserted in the polystyrene lid. Photo by David Varner.

Figure 5. Detail of the testing glass-rod waveguide. Note the bubbles on beaker bottom and walls. Photo by David Varner.

The distance of the waveguide tip from the beaker bottom was 2 centimeters. The acoustic response from the bubble development and bursting was monitored for 3 different water levels i.e. different immersion grades. Each AE measurement run was 10 minutes long. Between each consecutive runs 5 -7 minute intervals were applied. The actual measurement was initiated after pouring the water and about 30 second wait-time. Reason for this was to eliminate the influence of turbulent flow environment following the pouring.

During the stages, the obvious bubble behavior was observed including bubble development on the beaker inner surface, gradual growth and finally the detachment from walls and bottom. After a vertical upward motion, the bubbles hit the water line, causing severe acoustic impulses registered by the sensor on the waveguide. The entire AE measurement was repeated using two different AE analyzer slots: standard slot for 80-400 kHz range and updated low frequency slot covering 10-200 kHz range. Reason for this procedure was to determine optimal setup for effective AE signal reception. The table below lists individual measurement stages together with corresponding times of measurement.

AE analyzer slot type	**Water volume (ml)**	**Immersion zone length (cm)**	**Time of measurement**
Low frequency	400	3	11:11-11:21
Low frequency	600	5	11:24-1134
Low frequency	800	7	11:39-11:49
High frequency	400	3	1300-13:10
High frequency	600	5	13:15-13:25
High frequency	800	7	13:30-13:40

Table 1. Overview of the AE analyzer slots, water volume in the beaker, immersion zone lengths, and times of measurement.

In order to minimize influence of ambient environment, 50 Ohm terminators were used on remaining four channels of the AE analyzer. There is a salt corrosion chamber in adjacent room that might affect the measurement due to severe electromagnetic pulses generated by the salt mist generator switch. During the test, the following significant AE signal parameters have been taken into account:

RMS (Root Mean Square) indicates so called "effective" value or "energy" of the signal. RMS indicates quantity properties of the acoustic emission events. RMS is measured in Volts. In this experiment, RMS indicated perceptivity of the AE analyzer slot.

C2 count rate indicates amplitude range of the signal, as it registers crossings of the set threshold level. For this experiment, the C1 (lower level) was left out the evaluation. The C2 count was used to illustrate the rate more clearly.

PSD (Power Spectral Density) function maximum values of the AE events indicate distribution of energy transmitted over the frequency spectrum (similar to FFT showing the amplitudes over frequency domain). PSD graphs show one or more peaks. Transformation of the signal to frequency domain was done using the Hanning window. PSD is measured in mW/Hz or dBm/Hz for logarithmic scale. See the charts at the end of the paper for more information.

The Dakel XEDO AE analyzer was used in the experiment. Most configuration values were left on default settings, as listed in table 2.

AE Parameter	**Value**
Sampling frequency	4 MHz
Gain (analyzer)	40 dB
Gain (pre-amplifier)	35 dB
Maximum Range	± 2000 mV
AE Event Start Threshold	1200 mV
AE Event End Threshold	1200 mV
C1 Count Threshold	300 ‰ rozsahu
C2 Count Threshold	600 ‰ rozsahu

Table 2. Dakel XEDO AE analyzer configuration used uniformly during the experiment.

Results Overview

Two AE slots were used in the experiment with different immersion zones lengths and water volumes. For each slot, the AE record was analyzed to find optimal setup for real monitoring in the Destila micro-brewery conditions. The sensor used was the same for both slots.

As can be clearly seen in the AE charts below, each AE analyzer slot showed a different response to the AE signal. The charts show RMS values in blue and C2 counts in red. Note that the charts have the same axis settings, so that the values are visually comparable.

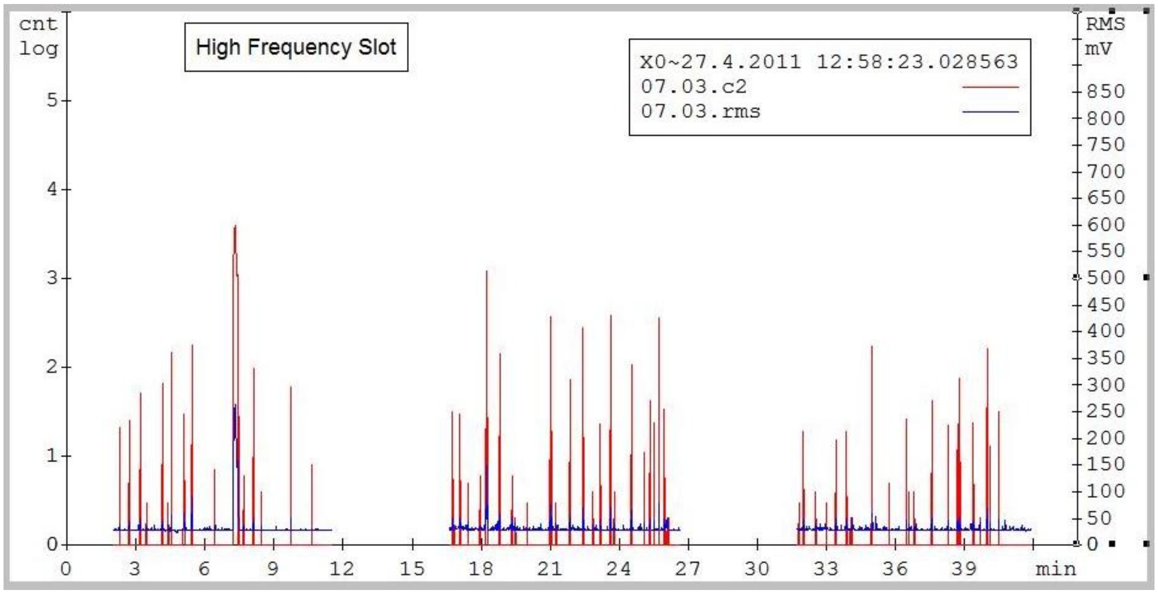

Figure 6. Chart of RMS and C2 values for standard AE analyzer slot. Note the three measurement stages and wait-times intervals.

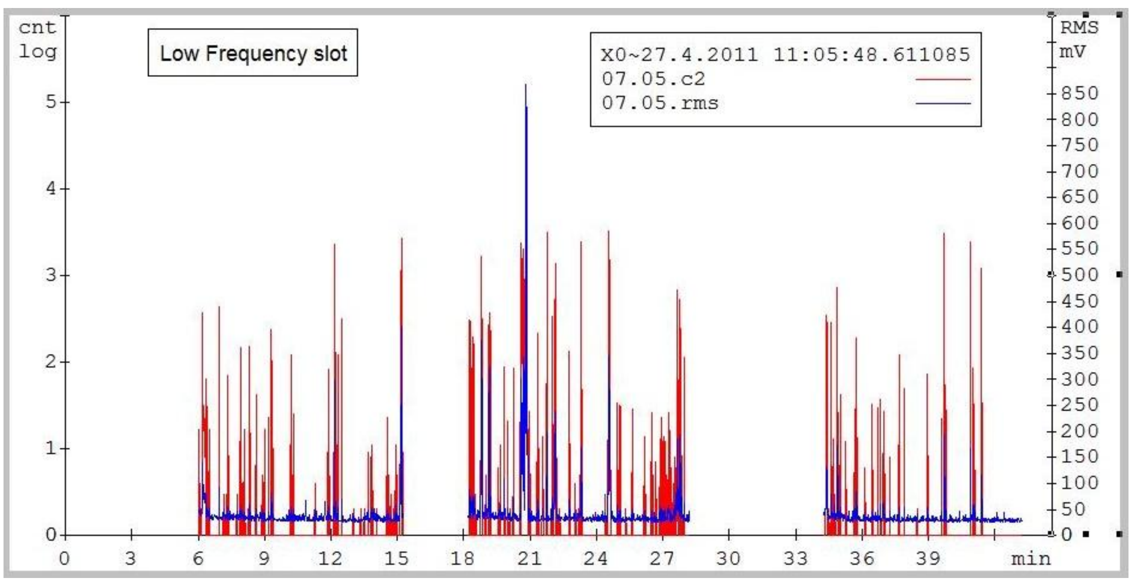

Figure 7. Chart of RMS and C2 values for updated low frequency AE analyzer slot.

The charts prove that the standard AE analyzer slot has much weaker response to the bubble-emitted signal than the updated low frequency slot.

In detail, we can see even a slight decreasing trend at the beginning of each measurement phase. This is obviously due to settling activity of the bubbles after initial turbulent flow conditions.

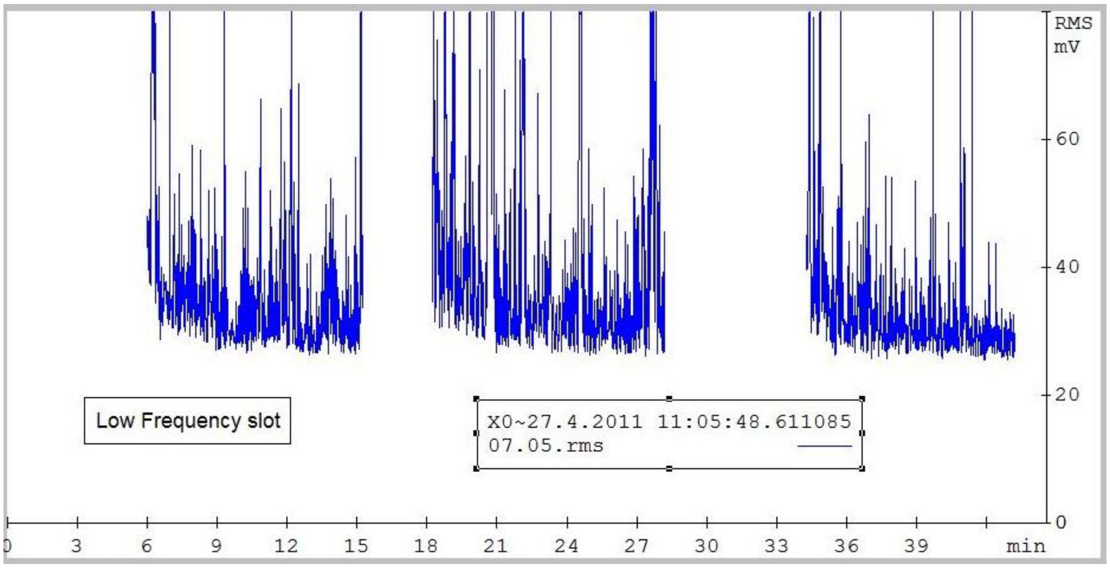

Figure 8. Detail of RMS record for low frequency AE analyzer slot. Note the decreasing trend in each measurement stage.

As far as the PSD function maximum values are concerned, there are several types of AE events. However, detailed signal sample analysis is beyond the extent of this paper. Four significant types of AE events could be identified in the entire dataset. These probably correspond to different modes of bubble disintegration. Below you can see the AE event samples and associated PSD function peaks. The amplitude on the left is in mV while the X-axis on the right represents frequency domain in kHz.

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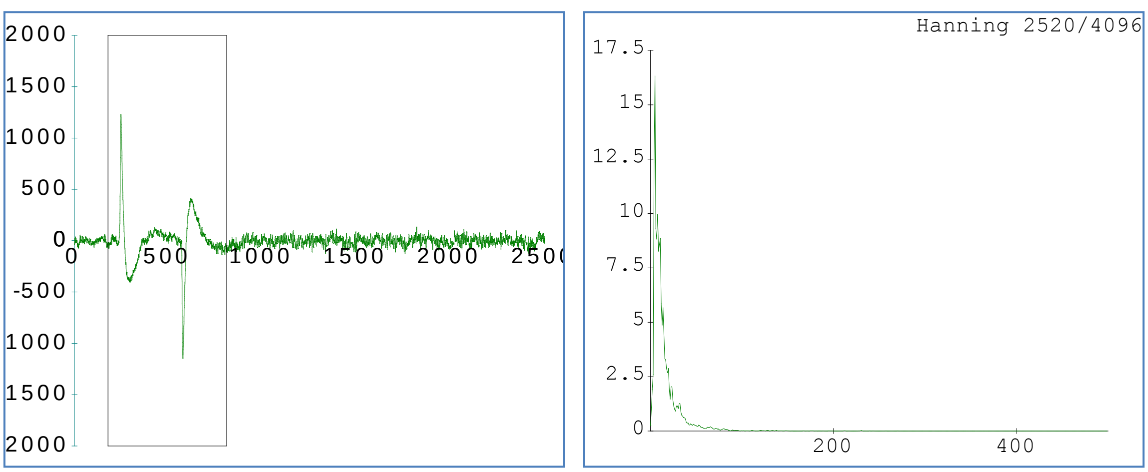

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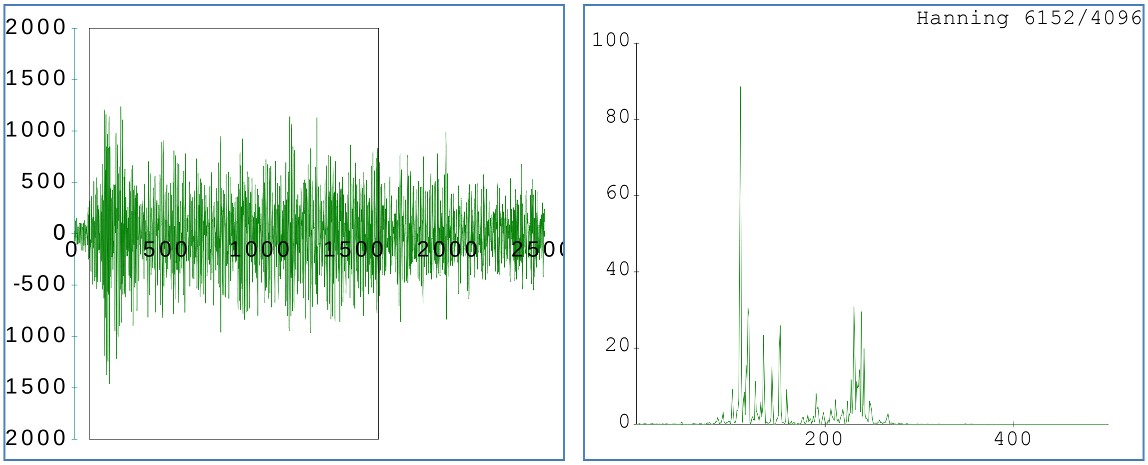

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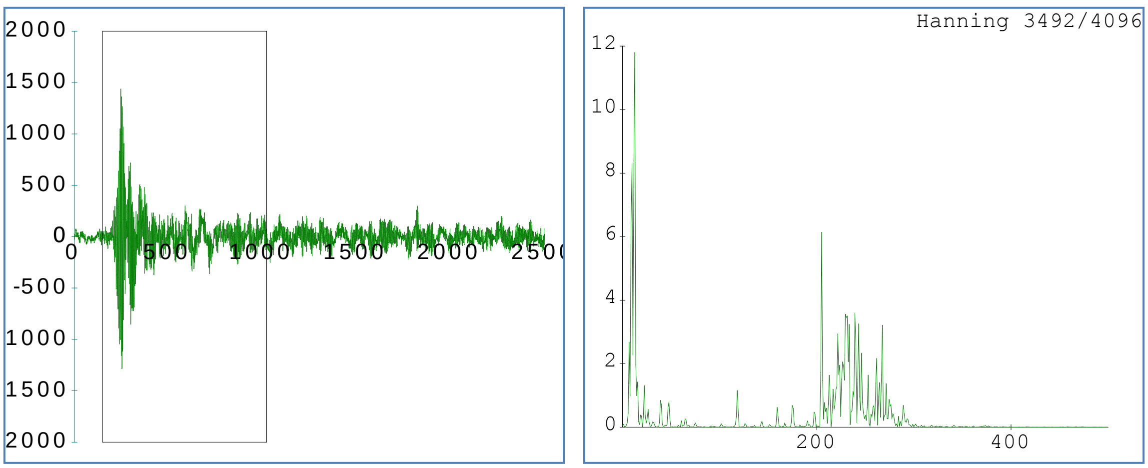

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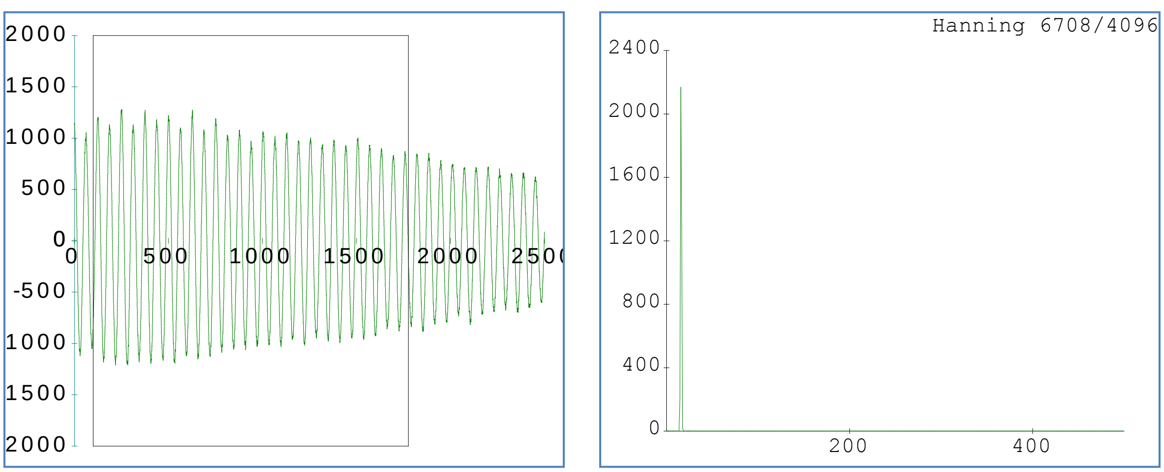

Figure 9. Four significant types of AE events obtained during the experiment. Note the Hanning selection window on the sample and corresponding PSD of the signal portion.

Based on the presented results, a real waveguide will be manufactured. This completely new design will include a clear perspex (plexiglas) disc precisely sized according to glass insert in the CCT observation openings. There will be a hole in the disc center accommodating the actual glass rod waveguide. Notches on the glass rod are going to indicate various immersion zones.

Conclusions

The experiment revealed several interesting facts concerning the usability of the glass-rod waveguide. Based on the signal reception level, low frequency AE analyzer slot was chosen for optimum performance of the system. Three different immersion levels were examined for the waveguide. It can be presumed that changes of hopped wort volume will have no significant effect on the waveguide functionality. Further testing will be performed in real Destila micro-brewery with real hopped wort batch and updated waveguide assembly inserted into the tank body.

References

[1] Beer Fermentation [online]. Available from WWW: < http://www.beer-brewing.com > [quot. 2010-09-26].

[2] KREIDL, M., ŠMÍD, R.: Technická diagnostika (Technical Diagnostics). 1. vyd. Praha : Nakladatelství BEN, 2006

[3] VARNER, D., ČERNÝ, M., MAREČEK, J., LOS, J.: Monitoring of Beer Fermentation Process Using Acoustic Emission Method. In *MendelNet 2010 Proceedings of International Ph.D. Students Conference*. 1. vyd. Brno: Mendelova univerzita v Brně, Agronomická fakulta, 2010, s. 651--659. ISBN 978-80-7375-453-2.