Listening concepts under extreme acoustic conditions in anechoic and reverberation chambers and underwater during aXes - Triduum of New Music Conference in Cracow

Bartłomiej Chojnacki, Adam Pilch, Aleksandra Majchrzak, Monika Sobolewska, Katarzyna Baruch

Department of Mechanics and Vibroacoustics, Faculty of Mechanics and Robotics, AGH University of Science and Technology in Cracow
bchojnac@student.agh.edu.pl

Abstract. Considering the end-user perception of music, acoustics is as important as any other component, obvious for a non-engineer listener, like timbre of the instruments, the harmony and the overall quality of a performance. In November 2015 a very special set of concerts was performed at AGH University of Science and Technology, where extreme acoustic conditions were presented. The same compositions were played in an anechoic chamber, a reverberation chamber and underwater, presenting to the listeners totally different perception of music, also the Ruben's Tube (also called a pyro tube) experiment with vocals/instruments was presented visualizing the standing wave phenomenon. The paper will explain the principles of used acoustic environments, including numerical simulation of underwater sound propagation. One of the used environments was AGH swimming pools, where the participants of the experiment were listening to the music underwater. Waterproofed loudspeakers were used to perform the concert; FEM simulations will explain how the music propagates underwater and how it influences the frequency response of the music. The project efficiently joined the scientific and artistic approach to the music - for the musicians to prepare and perform the compositions and the scientists to prepare and explain the acoustics. The overall evaluation of the performance was prepared and presented in the paper. Conclusions will discuss the objective and subjective changes in the perception of instruments and musical works, after scientific presentation of the acoustics influence on the listener.

Keywords. acoustics, reverberation chamber, anechoic chamber, underwater listening, underwater speakers, extreme acoustic conditions

1 Introduction

The conference aXes – Triduum of New Music (Sound. Space. Acoustics.) was held in the autumn of 2015 in Cracow. The idea of this event was to find a connection between two artistic groups: musicians and composers, creating a sort of an "axis" between them (the capital “X” in the name of the event symbolizes the point where both groups meet). The role of the main organizer was held by the Academy of Music in Cracow, and the participating composers and musicians originated from all over the Europe. The AGH University of Science and Technology was invited to take part in the conference, enriching the event by adding the element of science. The following paper presents the contribution to the event made by the Scientists of the Technical Acoustics Laboratory (TAL), which is a part of the Department of Mechanics and Vibroacoustics, AGH. The role of the acousticians was principally to organize and take part in the listening under extreme acoustic conditions, such as an anechoic chamber, a reverberation chamber and underwater environment at the AGH swimming pool.

2 Room acoustics perception

A term “acoustics” may be defined as the behavior of sound, the way it is perceived in time and space, and it is an inseparable part of the musical expression. The research described in the paper [1] indicates a need to introduce acoustics to the artists education curriculum, as the basics of this knowledge are essential in the work of a stage musician. It is often a case, that the problems arising on the stage result from an improper distribution of the musicians or even the choice of the instruments and the repertoire [2]; regardless of the instrumentation or music genre, the localization of the sound source is crucial [3],[4]. The experiments carried out in the acoustic chambers of AGH were aimed to present to the participants extreme situations – a case when no reflections are present and the listener experiences direct sound only (anechoic chamber), and the case when the localization of a sound source is impossible because of the acoustic diffuse field (reverberation chamber).

3 Laboratory conditions - anechoic and reverberation chambers

The idea of the performances at the AGH laboratories was to compare the same musical works presented under completely different acoustic conditions. The first room used for the experiment, anechoic chamber, is characterized by extremely short reverberation time and it attenuates all the sound reflections [5]. The inverse square law is also preserved, which means that the sound level decreases as given by the formula [6]:

$$p \sim \frac{1}{r^2} \tag{1}$$

When the inverse square law is preserved, the sound pressure level decreases by 6 dB when the distance from the sound source is doubled. A photo taken during the experiment is shown in Fig. 1.

Fig. 1. A concert in the anechoic chamber (*photo M. Bernas, KSAF AGH)*

In practice, placing a musical instrument in an anechoic chamber allowed hearing the instrument in its basic form, deprived of any room support. The notes were stopped short, impossible to sound in the chamber which attenuates any reflections of a sound wave. This led to the situation when the performance was perceived as dry and excessively detailed. Moreover, a low background noise in the chamber resulted in bringing out the noises generated by, for example, moving violin bow or the hiss of air inside wind instruments, which additionally enhanced the negative perception of the performance. The influence of the environment noise was described in details in [7] – in an anechoic chamber this type of noise is multiplied because of extremely low background noise which does not mask unwanted noises sufficiently. However, this kind of acoustic environment is very useful for the musicians while working on a desired tone color. Some of the phenomena which cannot be heard under concert conditions could then be perceived, which allowed more conscious generation of sound and better control over the acoustic events.

In the reverberation chamber, acoustic conditions were just the opposite. The underlying property of this room is based on the law of sound pressure level decay described by the equation [8]:

$$L = L_N + 10 \log_{10}\left(\frac{1}{4\pi r^2} + \frac{4}{R}\right) \tag{2}$$

where R is a so-called room acoustic constant, given by the equation:

$$R = \frac{S\,\alpha_{\mathrm{av}}}{1-\alpha_{\mathrm{av}}}\text{, where} \tag{3}$$

S – the surface of a room [m^2],
α_{av} – average sound absorption coefficient of a room.
When the value of α_{av} is very low, the sound pressure level L at the distance r bigger than several dozens of centimeters depends only on the acoustic power of the source

L_N. The acoustic field in the room is then called diffused; the majority of the sounds waves which arrive into the listener's ears comes from the reflections, not directly from the instrument [9]. The impulse response of the reverberation chamber at the AGH and a corresponding reverberation time are shown in Figs. 2-3.

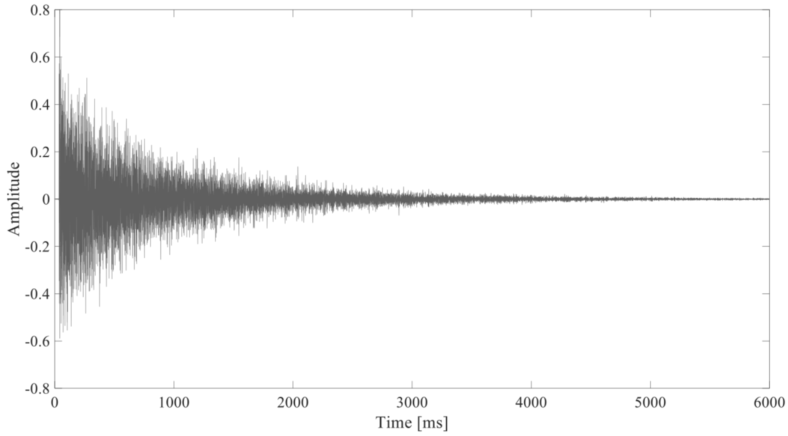

Fig. 2. Impulse response of the reverberation chamber, AGH

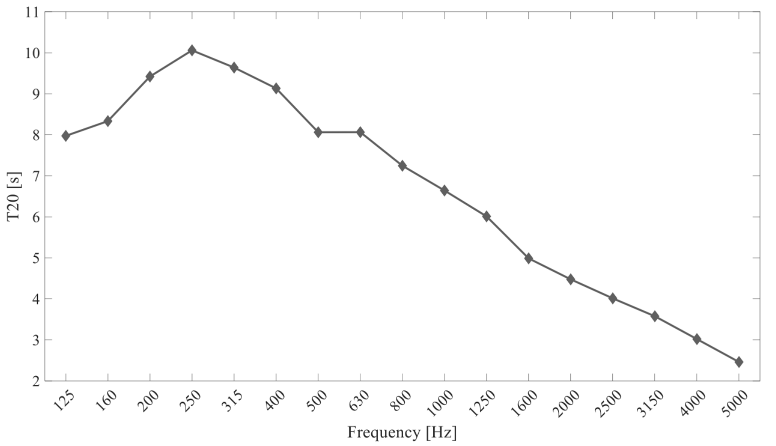

Fig. 3. Reverberation time of the reverberation chamber, AGH

A picture taken during a soprano concert in the reverberation chamber is presented in Fig. 4.

Fig. 4. A concert in the reverberation chamber (*photo M. Bernas, KSAF AGH)*

During the performance in the diffused field it was impossible to localize the sound source, and the substantial reverberation caused blurring the sound and losing all the details. The reflections from the walls enhanced the sound, and as a conclusion it was perceived as unnaturally loud. These conditions are only convenient for the musicians who play imprecisely and the properties of the room make the details blurry. In a properly designed concert hall, the equilibrium between a good sound source localization and sound propagation support should be maintained, using various acoustics shaping elements.

4 Underwater listening

The last experiment carried out at the aXes conference was an artistic performance in a form of a concert at the AGH swimming pool. In order to investigate the underwater sound propagation, a number of acoustic analyses were carried out, using hydrophones (underwater microphones), underwater loudspeakers and computer analyses. Fig. 5. shows the measured underwater impulse response of the AGH swimming pool, and Fig. 6. presents the reverberation time T20 calculated from this impulse response.

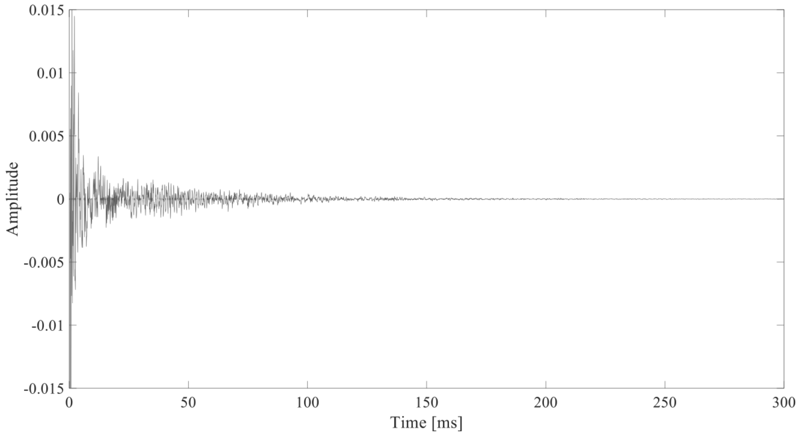

Fig. 5. The underwater impulse response of the AGH swimming pool

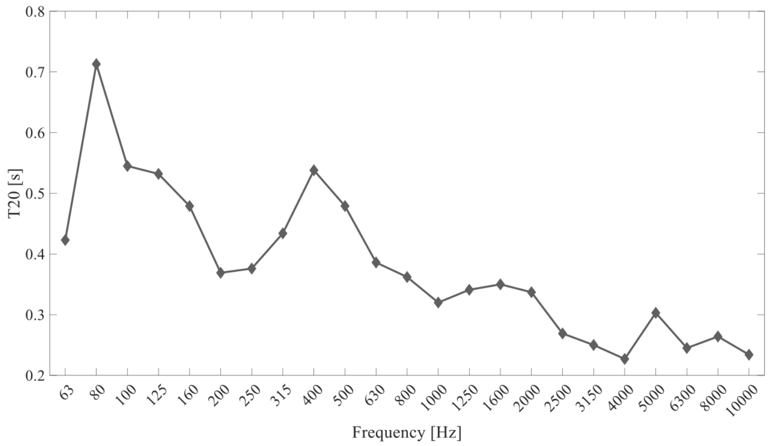

Fig. 6. Underwater reverberation time T20 of the AGH swimming pool, in 1/3 octave bands

The scientists of TAL performed a number of simulations using Finite Elements Method (FEM) in order to examine the phenomena of the underwater sound propagation. Fig. 7. presents a comparison of sound propagation in the air and underwater (the loudspeaker was placed above the water).

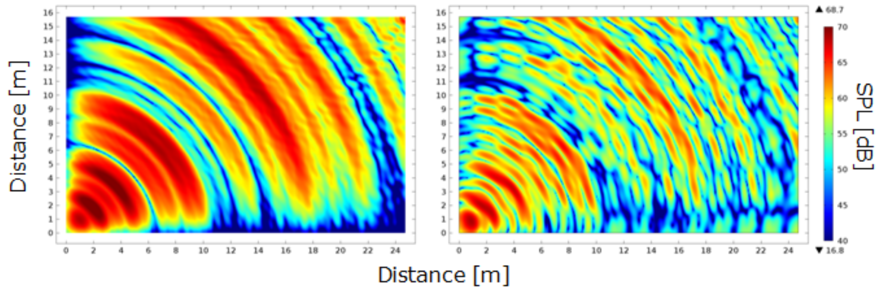

Fig. 7. Sound propagation in the air (left) and underwater (right), sound source above the water, frequency 500 Hz

A vast majority of the sound is transferred under the water, the differences between the sound levels in the air and under the water and minor. What is clearly recognizable, is the difference of the sound speed in the both media. In this particular experiment, more important was the effect of the calculations of sound transfer between the media (air and water). Fig. 8. Shows the results of the calculations for the sound source placed above the water, and Fig. 9. – for the sound source under the water.

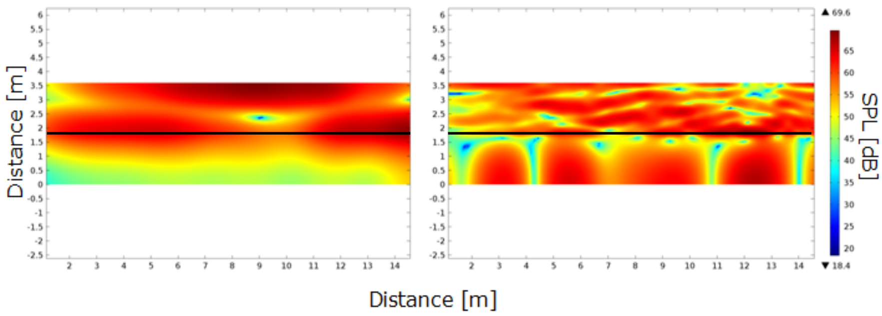

Fig. 8. A cross-section of the swimming pool; sound wave propagation under the water and in the air above the water, the sound source is placed above the water (frequency 125 Hz left, 500 Hz right). The air/water boundary is mark with a black line.

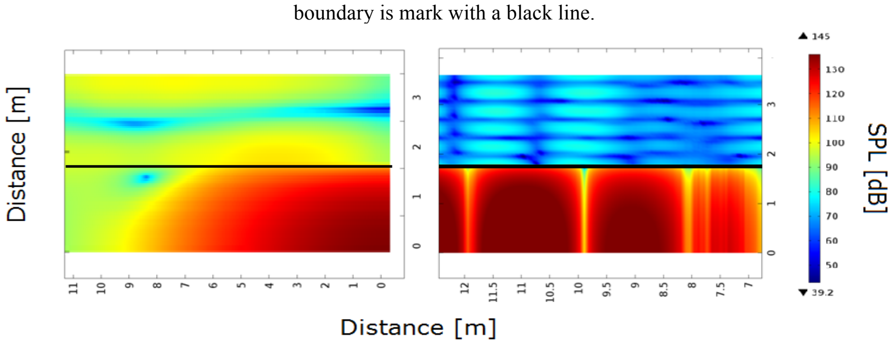

Fig. 9. A cross-section of the swimming pool; sound wave propagation under the water and in the air above the water, the sound source is placed underwater (frequency 125 Hz left, 500 Hz right). The air/water boundary is mark with a black line.

In the Figs. presented above one can notice that in the case of placing the loudspeaker above the water, the major part of the sound is transferred under the water. In the other case, when the loudspeaker is placed underwater, the difference of SPL between the media reaches up to 80 dB, which is explained by the difference of the impedances of the media. In the end, for the needs of the experiment, underwater loudspeakers were used to let the listeners perceive huge difference of sound level under and above the water. Fig. 9. presents the results of the calculations of SPL at the increasing distance from the source, which shows the general character of underwater sound wave propagation.

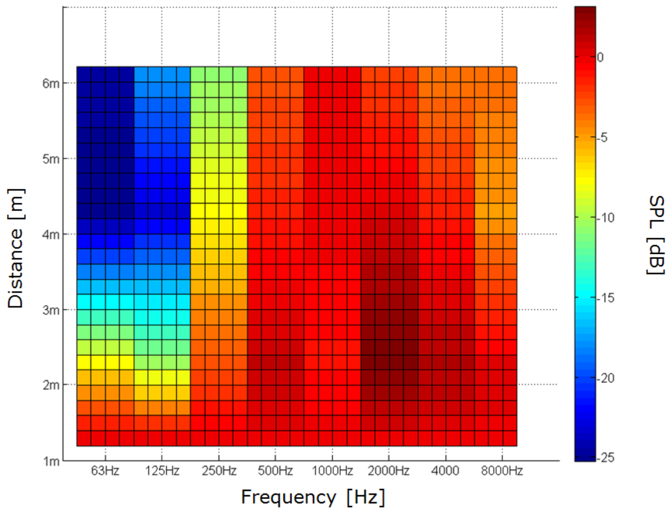

Fig. 10. Underwater SPL calculation results as a function of frequency and a distance from a sound source, 1/1 octave frequency bands

Analyzing Fig. 10., one can notice a quick decrease of SPL in low frequency bands, which corresponds directly with the attenuations of those frequency bands in the transmitted music. An interesting effect is a minor attenuation of high frequencies; because of that, at a bigger distance, the ratio between low and high frequencies is disturbed, which reflects the final perception of the concert in an interesting way.

During the concert the musicians were isolated from the audience space (swimming pool hall) and the sound was transmitted under the water electroacoustically, using underwater loudspeakers. The performance was preceded by a short lecture about the underwater sound propagation. The pictures from the concert are presented in Fig. 11.

Fig. 11. A concert at the AGH swimming pool (*photo M. Bernas, KSAF AGH)*

5 Rubens' Tube experiment

A Rubens' Tube is a physics apparatus used for the presentation of standing waves. One end of the tube is closed and at the other end – a sound source is placed. A length of the pipe is perforated – small holes are distributed evenly along the tube. It is supplied with a flammable gas which leaks from the perforations. During the performance, the gas is lit and the flames form in a shape of a sound wave because of the pressure generated by the membrane of the speaker. During the aXes conference, the musicians played their instruments, the sound was collected with microphones, and then fed to the sound source at the end of the Rubens' Tube which caused shaping of the flames. The musicians could shape the flames with their playing, choosing the notes and melodic lines, creating unique artistic and visual experiences. A photo form the concert is shown in Fig. 12.

Fig. 12. Rubens' Tube experiment (*photo M. Bernas, KSAF AGH)*

6 Summary

The experiments performed during the aXes conference allowed the increase of the consciousness on the room acoustics and its influence on the listener and the perception of music among the musicians and composers. This knowledge is especially important for the people in charge of the music scene; the choice of the musical programme should be made taking into account the possibilities of the room and its good and less favorable aspects. The performances showed the significance of the sound source localization and a proper reverberation time both for the musicians and the listeners. The conducted acoustic analyses and the performed experiments allowed introducing underwater environment as a new artistic mean, characterized by an interesting influence on the sound.

Acknowledgments

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