

# The influence of ultrasound signal parameters on sonoluminescence light intensity

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**Abstract:** Topics of this article concern the study of the fundamental nature of the sonoluminescence phenomenon occurring in liquids. At the Institute of Electrical Power Engineering at Opole University of Technology the interest in that phenomenon known as secondary phenomenon of cavitation caused by ultrasound became the genesis of a research project concerning acoustic cavitation in mineral insulation oils in which a number of additional experiments performed in the laboratory aimed to determine the influence of a number of acoustic parameters on the process of the studied phenomena. The main purpose of scientific research subject undertaken was to determine the relationship between the generation of partial discharges in high-voltage power transformer insulation systems, the issue of gas bubbles in transformer oils and the generated acoustic emission signals. It should be noted that currently in the standard approach, the phenomenon of generation of acoustic waves accompanying the occurrence of partial discharges is generally treated as a secondary phenomenon, but it can also be a source of many other related phenomena. Based on our review of the literature data on those referred subjects taken, it must be noted, that this problem has not been clearly resolved, and the description of the relationship between these phenomena is still an open question. This study doesn't prove all in line with the objective of the study, but can be an inspiration for new research project in the future in this topic. Solution of this problem could be a step forward in the diagnostics of insulation systems for electrical power devices based on non-invasive acoustic emission method.

**Key words:** diagnostics of insulating oils, sonoluminescence phenomenon, acoustic cavitation, ultrasound signal, acoustic emission signal

## 1. Sonoluminescence phenomenon in liquids

The phenomenon of cavitation is known as a formation of areas of discontinuity in a fluid, the so-called centers of cavitation bubbles in the form of vapor or gases dissolved in it due to local pressure drops below the critical value. Cavitation is a very complex phenomenon, it depends both on the physical and chemical properties of the liquid itself and of many external factors which may include the temperature and pressure [1, 2].

Ultrasonic cavitation is the formation of pulsating bubbles by a wave of high intensity ultrasound that arise as a result of local liquid ruptures due to high tensile forces occurring in

the phase of the wave rarefaction. The microscopic cavities quickly adopt spherical shape bubbles and are filled by diffusion with the saturated vapor molecules inside the liquid or gas dissolved therein [3-5]. For acoustic cavitation an important parameter is the notion of the cavitation threshold, above which this phenomenon can occur. Its value can be determined by vibration amplitude of the transducer, sound pressure or controlled transducer voltage [6-8].

Generally, the acoustic cavitation can be considered as a complex and stochastic physical phenomenon which occurs in the liquid exposed to an external acoustic field of a certain intensity and frequency. There is also the possibility of producing single cavitation bubble and maintain it in a liquid in a fixed position for a period of many hours. This property is often used in experiments for studying the single-bubble sonoluminescence phenomenon [9-11]. Generation of cavitation bubbles is also possible using a laser beam, therefore, the term optical cavitation applies [12, 13].

Cavitation as a result of impact of the ultrasonic signals of high intensity on the liquid is accompanied by numerous secondary phenomena of the mechanical, chemical, thermal and electrical nature. These phenomena are electrochemical phenomena, capillary, sonoluminescence and many others [14, 15]. Measurements carried out in laboratory conditions, the results of which are presented in this article refer for research of light emission and generation of acoustic waves that accompany the phenomenon of cavitation.

The phenomenon of cavitation in non-newtonian fluids is one of the main directions of research projects conducted by major research centers in the last decade. Based on the work [16-18] shows that the addition of polymers to the tested liquid influence the cavitation. In the case of newtonian liquid estimation of the intensity of cavitation is relatively difficult issue. A method based on a visual interpretation of the cavitation bubbles is not sufficient due to the phenomenon of pseudocavitation, which occurs for example in polymer solutions [19-21].

Acoustic cavitation was studied in liquids such as glycerin [22], toluene, cyclohexane, benzene, kerosene, and many others [23]. In practice, it is difficult to unambiguously determine whether the clouds of cavitation bubbles come from pseudocavitation or as a result of degassing. Therefore, in studies of cavitation, spectral analysis of recorded cavitation noise is very often used [24].

Studying the dynamics of microscopic bubbles in liquid insulation were also performed for the corona partial discharges. In these works, the influence of the acoustic wave emission during the final phase of the collapsing bubble was analyzed. Also the impact of liquid viscosity on damping of insulating gas bubbles was analyzed [25].

## 2. Measurement setup

An experimental apparatus has been designed and built in our laboratory that allows us to carry out sonoluminescence experiments and to obtain the light intensity and acoustic emission dependencies on voltage and driving ultrasound frequency in fluids. The schematic diagram of used measurement device was previously published in several papers [26, 27]. Designed and constructed measurement system can be divided into the following functional blocks:

- cavitation vessel,
- unit for generation of acoustic cavitation,
- secondary control unit,
- measuring unit of acoustic emission signals,
- very low light intensity measuring unit,
- camera with long exposure time,
- software for supervising of the measurement process,
- software for the analysis and visualization of measurement data.

The main part of the measurement setup is a sine wave generator based on a high performance DDS (Direct Digital Synthesis) AD9850 synthesizer with amplitude and frequency tuning capabilities. This solution results in an output frequency tuning resolution of 0.1 Hz. An external digital-to-analog converter (TLV5638) connected through a serial interface to an MSP430F149 microcontroller has enabled the amplitude tuning capability. The reference input of the DDS generator was driven by the output voltage of the DAC. The DAC with 12-bit resolution enables to achieve a satisfied amplitude tuning resolution. The low voltage (several volts) sine signal from the generator is amplified by a two-stage high voltage amplifier supplied by a 1600 V power supply and connected to the piezoelectric transducers. The sonoluminescence light intensity was measured by a high sensitivity photomultiplier tube.

### 3. Measurement results in water

Figure 1 depicts two cases of used water filled cavitation vessel. Part a) presents the cavitation flask in normal lighting conditions. In this case the cavitation areas with low intensity sonoluminescence emission were not visible. The part b) of the figure presents the image created by a high resolution NICON D50 digital camera after 30 minutes of exposure time in dark environment. The effect was an almost symmetric light source in form of two larger and two smaller luminous areas present in constant distance from the driven transducers. In both presented cases the transducers were driven by a 132 kHz frequency and 900 V rms value sine signal from the high voltage amplifier.

Figures 2, 3 and 4 depict the dependence of sonoluminescence light intensity on signal frequency in the whole available frequency range from 0 to 200 kHz at three levels of transducer driving voltage, respectively 300 V, 600 V and 900 V. The multi-bubble sonoluminescence light were observed for frequencies between 50 kHz and 140 kHz and signal amplitudes up to 1000 V. At transducer signal voltages above 1000 V and frequencies above 140 kHz no light were observed. The most intense light (as presented in Fig. 4) of sonoluminescence in distilled water were observed for a signal with about 132 kHz frequency and 900 V rms value.

It is worth noting that the sonoluminescence light intensity measured as a signal level from used high sensitivity photomultiplier tube is not constant in the mentioned frequency range between 50 kHz and 140 kHz. The light intensity has a form of several pulses with different intensity level. The higher the driven voltage the higher the intensity of light peaks.

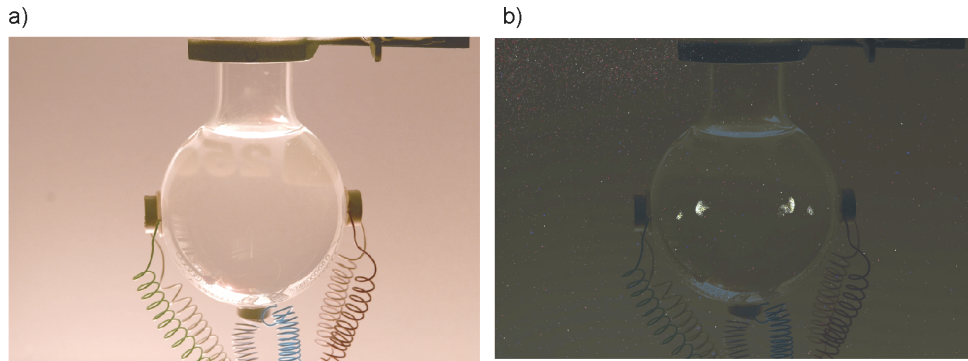


Fig. 1. Water filled cavitation vessel with glued piezoelectric transducers for both acoustic field generation and measurement in normal lighting conditions (a) and dark environment using double exposure (b) with visible symmetric luminescence areas

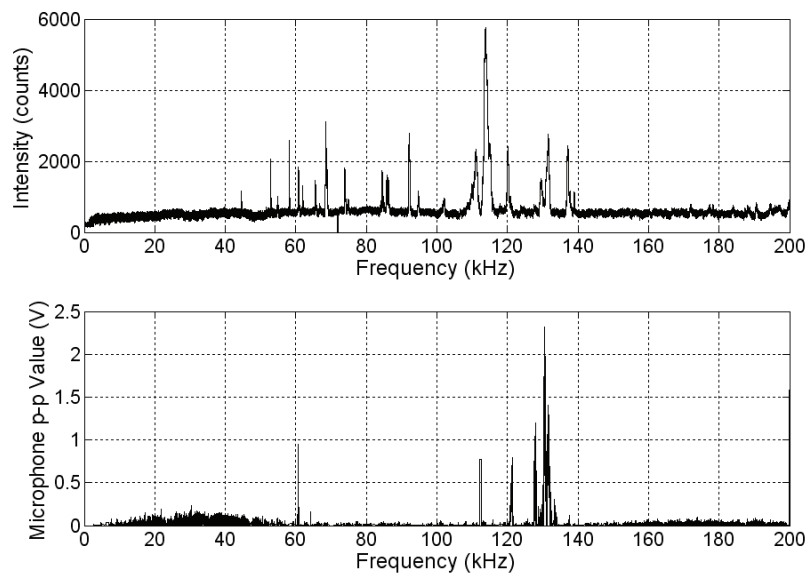


Fig. 2. Dependence of measured sonoluminescence light intensity and measured piezoelectric microphone peak-to-peak signal value on generated (connected to transducers) acoustic signal frequency at constant voltage of 300 V

For both sonoluminescence and acoustic emission research a third piezoelectric transducer was glued at the bottom of used cavitation flask in the centre of two acoustic wave source transducers. The microphone peak-to-peak signal is useful for observation of acoustic field intensity inside of the cavitation vessel. The dependence of sonoluminescence light intensity and microphone peak-to-peak value on signal frequency at 300 V is presented in Figure 2. It can be clearly seen that there is no direct relation between these two signals at 300 V. At 600 V rms value the comparison results are similar (Fig. 3). However at driving rms value of 900 V, at which the most optimal conditions for sonoluminescence research were present, the correlation between the sonoluminescence intensity and microphone signal is very high (Fig. 4).

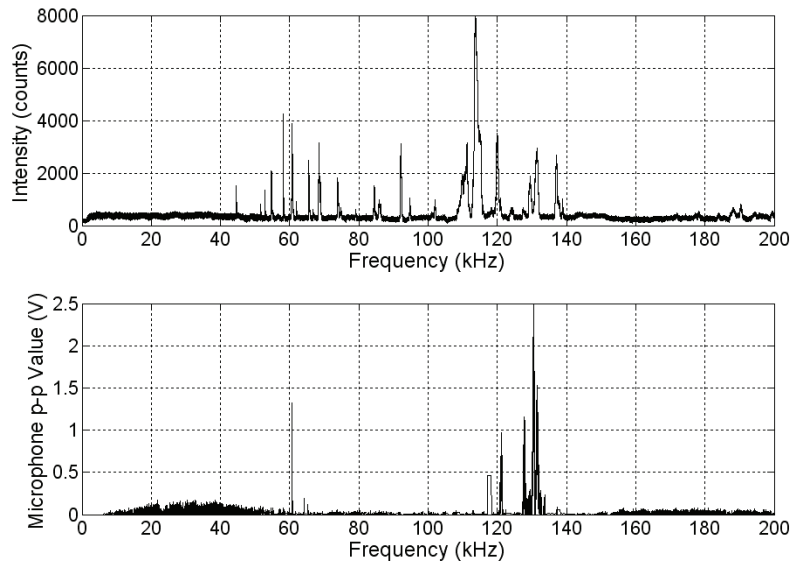


Fig. 3. Dependence of measured sonoluminescence light intensity and measured piezoelectric microphone peak-to-peak signal value on generated (connected to transducers) acoustic signal frequency at constant voltage of 600 V

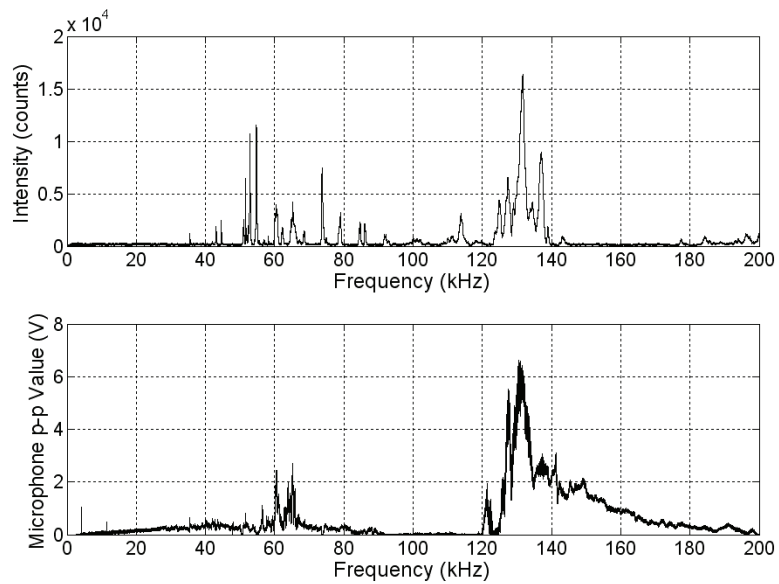


Fig. 4. Dependence of measured sonoluminescence light intensity and measured piezoelectric microphone peak-to-peak signal value on generated (connected to transducers) acoustic signal frequency at constant voltage of 900 V

The observation of the microphone p-p value in Figures 2-4 show that two distinct frequency ranges are dominant: 40-80 kHz and 120-140 kHz at all three rms values.

For the cases of 300, 600 and 900 V, the resonance frequency of the whole system was 130 kHz and a half (~60 kHz) when the acoustic emission was observed. It should be mentioned that the acoustic emission signal was not measured by a hydrophone immersed into the liquid, but by the third piezoelectric transducer glued at the bottom of the glass flask visible in Figure 1. On the other hand, it seems to be 115 kHz and a half (~60 kHz) when sonoluminescence light was observed. Thus, the resonance frequency of the system seems to depend on the method of observation, but in our opinion in the system it is not the case. Such symptoms can be caused by some local resonance frequencies of some parts of the system i.e. irregularities in glued source transducers, acoustic signal generator and others. In our opinion the light peaks at 115 kHz in case of 300 and 600 V were not really dominant and were not the result of the resonance frequency of the system.

The left side of Figure 4 enlarges the dependence of sonoluminescence light intensity on signal frequency in the range from 40 kHz to 80 kHz at 900 V signal amplitude. The maximum light intensity in this window can be seen at frequencies of 53 and 55 kHz. The rest of frequencies are characterized by weaker light emission process. The second specified signal frequency range (120-140 kHz) are enlarged in right side of Figure 4. The sonoluminescence light was observed at almost whole frequency range. Four local maximal values are present at following signal frequency values: 125 kHz, 127 kHz, 132 kHz and 137 kHz. Piezoelectric transducers driving signal with 132 kHz frequency and 900 V rms value caused the most intense sonoluminescence phenomenon in used distilled water filled cavitation vessel.

### 3. Measurement results in other liquids

Research on the phenomenon of sonoluminescence were also carried out in liquids described in the literature as more suitable from the excitation view and more stable in time, for example distilled water with a small amount of glycerin was often used. Figure 5 shows a photo taken by a camera after 30-minute exposure time. It shows definitely more of the emitting areas, characteristic is also the color of the spots similar to light blue.



Fig. 5. The multibubble sonoluminescence light intensity in a flask filled with water and glycerin

It should be noted that during the research project the authors of the article have made many attempts to observing sonoluminescence phenomena in insulating mineral oil, but unsuccessfully. Although long hours of observation there were no clear luminescence areas despite the use of new insulating oil. The mentioned research project concerns mainly the acoustic cavitation spectra measurements already published [27-31].

#### 4. Conclusion

Insulating liquids due to their physicochemical properties are not conducive to the formation of the light generated by the sonoluminescence phenomenon. However, it is possible to observe the acoustic emission signal which always occur during acoustically induced cavitation. The observation of this signal also allows to draw conclusions about the insulating liquid used, in particular, its parameters characterizing a considerable degree of aging of oil, that have a darker color.

The results from experiments in water presented in this paper should be treated as the results of a control experiment that confirms the effectiveness of used cavitation vessel and the whole acoustic signal generation unit designed and built during the research project.

The subject of this paper concerning sonoluminescence in liquids was not exhausted. There are no attempts to explain the bubble sizes produced, uniformity of bubble sizes, bubble coalescence etc. Also the sonoluminescence experiments in insulating oils have given no positive results. It should be noted that the mentioned research project concerns mainly acoustic emission measurements during ultrasound cavitation in insulating oils. Attempt to produce sonoluminescence in such medium is additional and also unique, because it does not was so far the subject of extensive research.

The primary scientific objective of research topics taken was to date not resolved. It deals with the mutual relationship between optical and acoustic phenomena in the broader diagnostics of electrical insulation systems between partial discharges, formation of gas bubbles and accompanying acoustic emission. Results presented in this article are the next stage of the research on this issue.

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