Approach to Quantify Acoustic Cavitation in Absolute Physical Units

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Abstract

In the study of acoustic cavitation it is desirable to quantify the acoustic signals in physical units to allow comparison among different conditions regardless of the equipment used. Motivated by cavitation present in cleaning environments, we have developed a method to measure the acoustics of cavitation in a way that is independent of the instrument used. The proposed method is based on having a point-like pressure sensor (hydrophone) calibrated in magnitude and phase over a broad frequency spectrum (well beyond the driving field frequency), capturing a limited sample of the raw time domain signal (in V), and converting the sample to frequency domain. The spectral decomposition of the raw signal is then used to deconvolve the sensor response to generate the true spectrum of the detected pressure field (in Pa). In the frequency domain, the corrected spectrum reveals the direct field as a single frequency signal, the stable cavitation by the sub-harmonics, harmonics and ultra-harmonics, and transient cavitation in the form of broadband noise above the electronic noise. By selectively integrating the various frequency components it is possible to know the acoustic pressure, in RMS units of pressure (Pa), for the direct field, stable cavitation, and transient cavitation. We present practical examples of measurements under various cleaning conditions where one can observe the effects of driving power, location relative to the source, or distribution of objects to be cleaned in the tank. It is believed that this or other method based on true, absolute pressure measurements will allow more progress in the research of cavitation by providing a means to exchange and compare quantitative data.

Keywords: Acoustic Cavitation, Stable Cavitation, Transient Cavitation, Measurement

Introduction

Acoustic cavitation is widely used in industry due to its effects on solid surfaces[1]. In cleaning processes the transient (or inertial) cavitation is often associated with deep cleaning or damage to the surface or structures on it, due to the violent collapse of bubbles, while stable cavitation provides a more gentle cleaning effect due to microstreaming. Distinct techniques to measure and detect the acoustic cavitation have been used [1,2]. While various kinds of hydrophones have been used to measure the acoustic field, and the cavitation activity has been evaluated in the frequency domain, the absence of real voltage to pressure calibration only allows measuring in electrical units (in V), which is not physically meaningful because it is dependent on the sensor used.

The proposed method to quantify the stable and transient cavitation levels is based on spectrally analyzing the acoustic emissions with a hydrophone that is small relative to the dominating wavelength, rugged enough to survive the environment, and calibrated in magnitude and phase over a broad frequency spectrum well beyond the direct field frequency. The signal is converted to the frequency domain (in V) which is then used to deconvolve the sensor response to generate the true spectrum of the detected pressure field (in Pa). A sample pressure spectrum can be seen below (Fig. 1). The primary peak colored in blue represents the direct field frequency (F_0) and pressure (P_0), the yellow peaks corresponding to harmonics and subharmonics of the direct field represent stable cavitation pressure (P_s), and the red colored region represents the signal from the bubble collapse or transient cavitation pressure (P_t) [3]. Uniquely quantifying both P_s and P_t is integral to monitoring and controlling an ultrasonic cleaning processes.

It should be noted that the acoustic field in a cleaning tank is not static, as the direct field is subject to reflections off the walls and the air above, and variations in the surface shape change the reflections and therefore the patterns of interference between the reflected waves. To obtain meaningful measurements one must take readings over an extended time window that incorporates enough of the fluctuations in order to obtain an average reading. The time of observation, as in other processes that include randomness, needs to be judiciously determined depending on the characteristics of the environment. The cleaning process, after all, relies on the integrated effect of the pressures on the particles, over the time used for cleaning.

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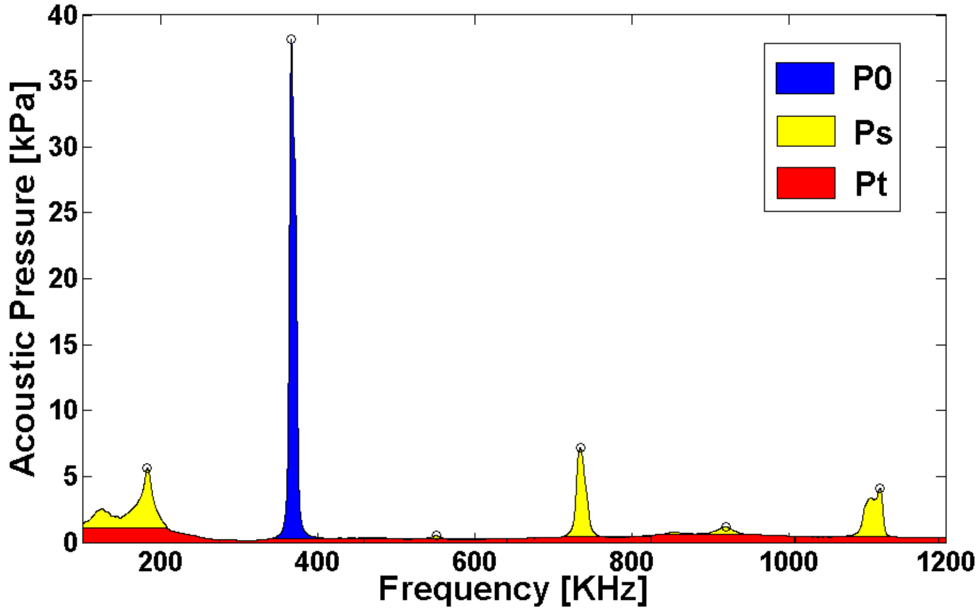

Figure 1. Acoustic pressure spectrum example. The blue area represents the direct field pressure (P_0) generated by the driving source at its fundamental frequency (F_0). The yellow areas represent harmonics, sub-harmonic and ultra-harmonics associated with stable acoustic cavitation pressure (P_s). The red area represents the broadband noise generated from the collapse of bubbles, or transient cavitation pressure (P_t).

Materials and methods

A hydrophone (HCT-0310, Onda Corporation) was used to acquire the electrical signal in a cavitation environment. The hydrophone sensing area is about 1 mm in size, appropriate for direct fields up to 1 MHz. The hydrophone is connected to a cavitation meter (MCT-2000, Onda Corporation) which has an electronic bandwidth of 10 MHz and acquires the acoustic pressure spectrum to determine measurement parameters including P_0, P_s, P_t and F_0. Figure 2 shows the process steps used to obtain the cavitation acoustic parameters.

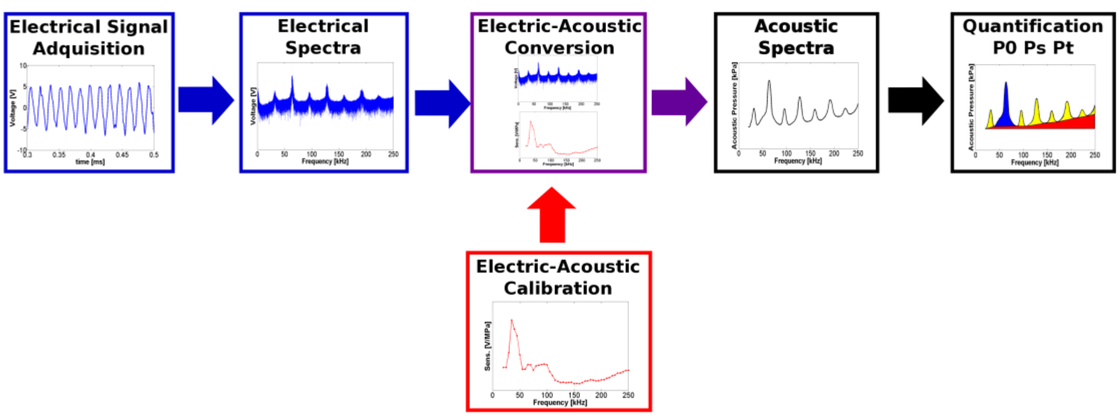

Figure 2. Processing steps to quantify the cavitation acoustic parameters.

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Results and examples

We present examples of measurements under various cleaning conditions in Figure 3. Fig. 3(a) shows the cavitation pressure for several driven frequencies (36, 78, 118, 132, 172, 215 and 265 [kHz]) using approximately the same power density. In Figure 3(b), the cavitation pressure is measured at varying electrical power levels for a 78 [kHz] tank.

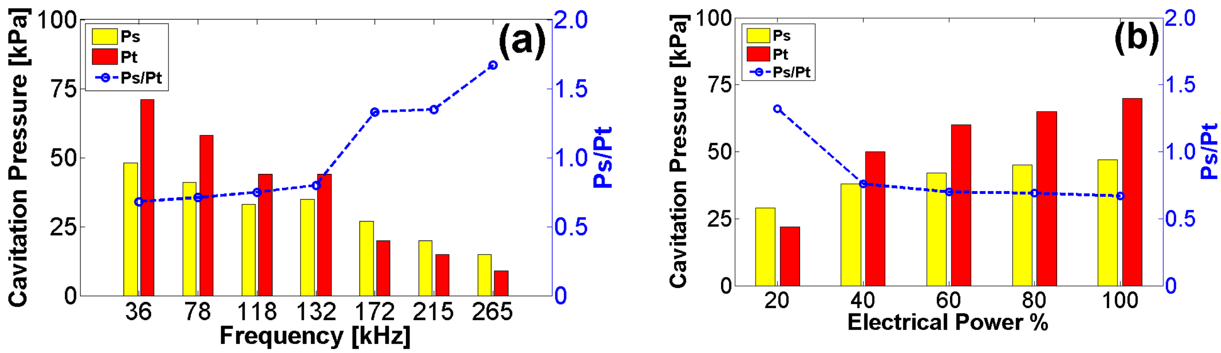

Figure 3. (a) Stable and transient cavitation comparison at different frequency. (b) Stable and transient cavitation readings in a 78 KHz tank as a function of the electric power.

To investigate the uniformity of the acoustic field in a 160x80mm, 40 KHz cleaning tank, the direct field pressure was mapped at intervals of 5 mm, creating a mesh of 17x33 points (Figure 4). This is a quantitative equivalent of the aluminum foil test [4].

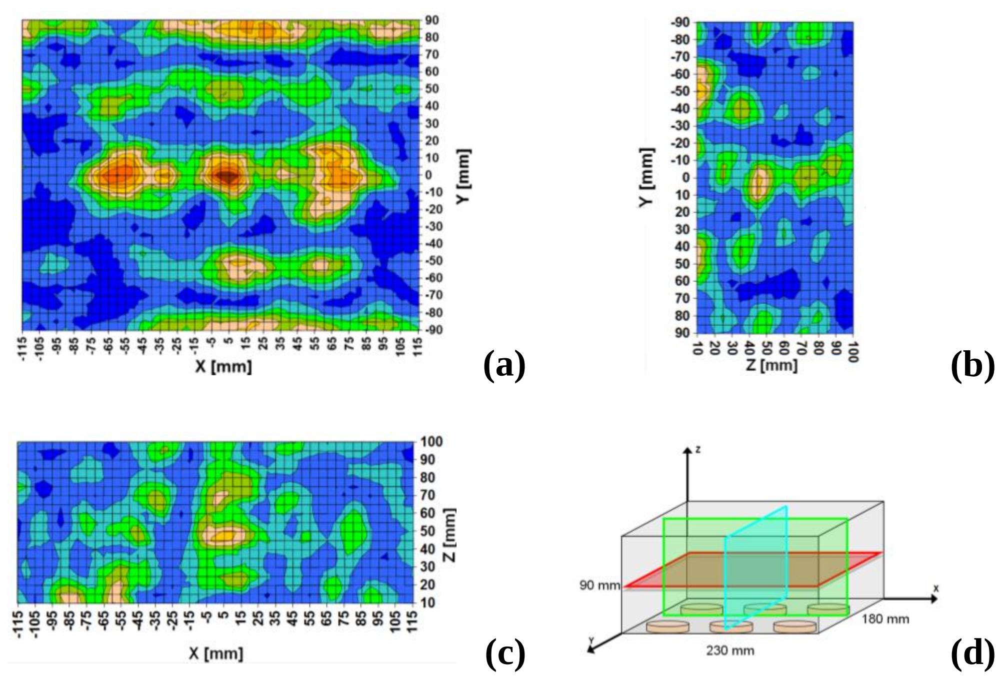

Figure 4. (a) Normalized P_0 uniformity mapping for XY plane, (b) YZ plane and (c) XZ plane and (d) Schematic of cleaning tank showing scanned planes.

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Effect of the presence of objects in a tank

To understand the effect of the presence of parts in the acoustic field, the mapped cavitation pressure distribution in 40 kHz cleaning tank that is used to clean disks in cassettes is shown in Figure 5. The map is made in the plane next to where a disk is located, in the tank with water but otherwise empty (a), then adding an empty cassette (b) and cassette with 14 discs (c).

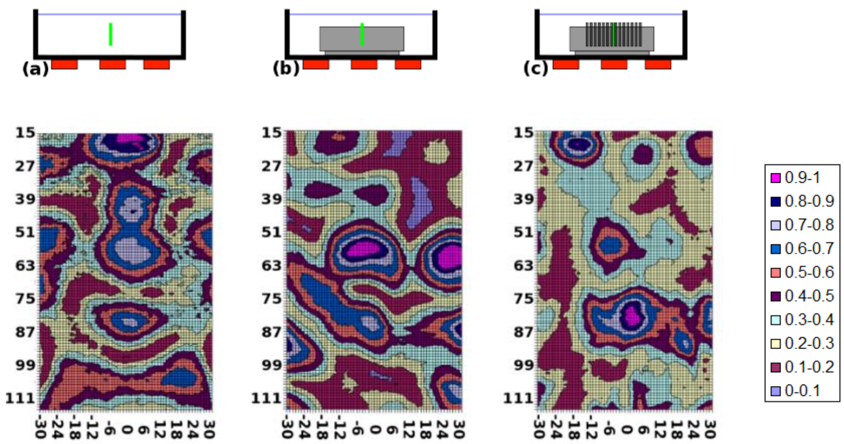

Figure 5. Loading effects on acoustic uniformity 40 kHz batch system (a) empty tank, (b) added an empty cassette and (c) added 14 disks to the cassette.

The drastically different patterns over the same plane shows that the effect of the presence of cassette and disks must be taken into account when evaluating the cleaning performance.

Conclusion

The ability to measure cavitation in its separate components and in absolute units has been demonstrated, and we propose that this or similar methods be employed in quantifying cavitation acoustics. The key elements are a durable sensor that is smaller than $\lambda/2$ (for isotropy) and calibrated (in V/Pa) over a wide range of frequencies. The range should extend from below the driving frequency to a few MHz, as transient cavitation has been observed in this range [3,5]. Processing must be done on time samples that are long enough to smooth over fluctuations of the acoustic field (usually of the order of 1 second) and short enough to provide timely information (in the order of few seconds).

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