Pressure Pulse Fields: Comparison of optical hydrophone measurements with simulations using FIELD II

Abtin Jamshidi Rad, Friedrich Ueberle

HAW Hamburg, 21033 Hamburg,

E-Mail: Abtin.Rad@live.de, Friedrich.Ueberle@HAW-Hamburg.de

Introduction

Prediction on the efficacy of an ultrasonic medical treatment device needs measurement of the field parameters. The measurements are carried out by hydrophones in degassed water. Two groups of hydrophones are available, the piezoelectric- and the piezooptic hydrophones. The robustness and the ease of use as well as the ability to measure negative pressures make the optical hydrophones the sensor of choice for high pressure pulse fields.

While measurements are needed to characterize the field of an ultrasonic device, simulations are needed in the development period to predict the field of the same. Several approaches for simulating ultrasound are available. While finite and boundary element methods are very effective and flexible tools for simulating a variety of sound problems, the computing-power requirement and the prime cost are still very high. As long as the sound propagation occurs in the linear range the emitted and the scattered field can be calculated using spatial impulse response.

In this paper we compare the measurements of two optical hydrophones, the Light Spot Hydrophone and the Fiber Optic Hydrophone, with simulations using FIELD II [1] [2].

Physical principles

Measurements of ultrasonic fields are often performed using PVDF membrane hydrophones. PVDF is a piezoelectric material and is preferably used for hydrophones due to its high sensibility and high bandwidth. The disadvantage of PVDF hydrophones are the hydrophobic properties of the membrane surface and hence a poor ability to measure negative pressures. [3] The hydrophobic properties of the membrane abet the occurrence of cavitation in the fluid and consequently destroying the hydrophone. To avoid averaging effects the sensor element diameter should be in the sub-millimeter range. Due to fringe effects, PVDF sensor element diameters below 0.5 mm are difficult to realize. [4]

The first approach for robust optical hydrophones arrived with the fiber optic hydrophone (FOPH). The principle of FOPH is based on the change of light reflectivity at the end-face of a fiber, when the incident wave passes the fiber tip. The pressure wave changes the mass density of the fluid and the fiber, which in turn modulate the refractive index. Laser light is coupled into the fiber and the reflected part is measured by a photodiode. The electrical signal of the photo-detector represents the pressure-time-development at the location of the fiber tip. [4] The FOPH shows good results for pressure and energy estimation. [3] Advantages of the FOPH are the high adhesion between the sensor and water, the small diameter of the fiber tip and the high bandwidth of the sensor which is mainly limited by the photodiode. Unfortunately, with fiber-diameters less than 100 µm the fiber tends to break during measurements in presence of high peak pressures, which leads to complicated recalibration of the sensor. [3]

The LSHD is based on the same principle as the FOPH with some enhancements regarding the stability and the ease of recalibration of the sensor. The sensitive area of the hydrophone is a laser light spot at a water-glass interface. At the glass-water interface of a solid glass block the pressure variation changes the density of the medium and hence the refractive index, which modulates the intensity of the reflected light at the interface. The transformation of the reflected light into an electrical signal by a photodiode reproduces the pressure history at the spot position. [3]

In both cases the hydrophone output voltage depends only on the reflectivity parameters at the interface and on the electronic properties of the system. Due to the low compressibility of the solid material, in contrast to the high compressibility of water, the change of refraction in the solid material can be neglected. [4] The calibration of optical hydrophones is completely defined by the material properties, and there is no need of frequent calibration with reference hydrophones.

Mathematical principles

FIELD II is a simulation program for ultrasound fields. The program is citation-ware, thus a reference to the two papers [1] and [2] and the name of the program has to be mentioned in the publication. FIELD II calculates the emitted and the received pulse-echo signals of ultrasonic transducers by implementing the spatial impulse response.

The impulse response is widely used to describe a linear electrical system, where the electrical output of the system is given by the time convolution of the input signals with the impulse response of the system. The same principles are applied for a linear acoustic system. [5] The pressure field of a transducer at a specific point in space without damping is found by the time convolution of the electrical excitation of the transducer – electrical excitation to surface velocity – with the spatial impulse response, determined by the geometries of transducer and sensor position in the sound field.

Experimental Setup

The measurements are done in degased and deionized water with constant temperature of 25°C. The Panametrics 5 MHz NDT Transducer is placed in a water tank. A GE

Panametrics Squarewave Pulser (GE Panametrics Walthem, MA) is used to drive the transducer. Measurements are done with the Light Spot Hydrophone LSHD-2 (Siemens Erlangen and University of Erlangen) and a fiber optic hydrophone FASO-01 (Siemens Erlangen) and recorded with an HAMEG 1508-2 oscilloscope. The same transducer was measured at PTB in Braunschweig using a Laser-Interferometer-Hydrophone. This calibrated hydrophone is used for comparison.

Results

The FASO measurements show that the signal is heavily distorted and the peak-pressure amplitudes are more than doubled. The LSHD measurements show good representation of the transducer field (Figure 1); however it overestimates the negative part of the pulse. This has also been noticed by N. Smith et al. [6], though there is not yet an explanation for this phenomenon.

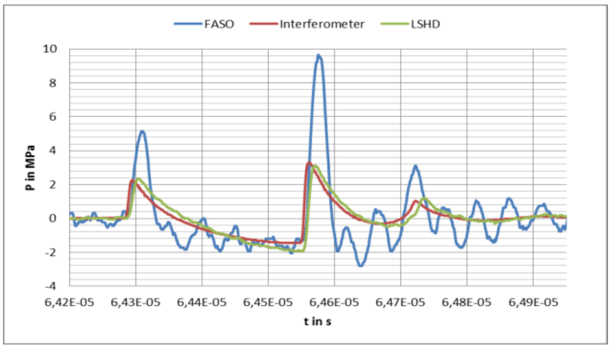

Figure 1: Comparison of optical hydrophones at 400 V excitation of the transducer.

The signal distortion of the FASO arises from the transfer function of the sensor as well as the impedance mismatch at the fiber and water boundary. Another fact is the poor signal-to-noise ratio of optical hydrophones at low pressure levels.

After de-convolving the FASO signals with our own de-convolving algorithm, the signal show good agreement with interferometer measurements (Figure 2). It is obvious that the FASO suffers still from the low signal-to-noise ratio despite long signal averaging, which is a drawback of refractive type optical hydrophones when used for low pressure field measurements.

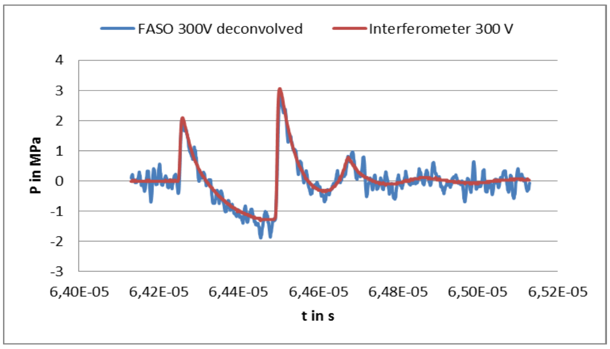

Figure 2: The FASO measurements after de-convolving of the signal. Despite averiging of 64 measurements a significant noise level remains.

Simulation using the theory of spatial impulse response (applied in FIELD II) implies linear sound propagation without steepening. This is not the case in our setup, with high excitation voltages. However with low excitation voltages the steepening and non-linear effects are not distinct, thus we try to simulate the transducer in FIELD II. As obvious even at low excitation voltages steepening and non-linear effects occur, and hence FIELD II simulations lead to inexact results (Figure 3). In addition improper approximation of the transducer impulse response worsens the output. In these non-linear cases other simulation techniques, such as Finite Element Methods need to be used, in order to provide accurate results.

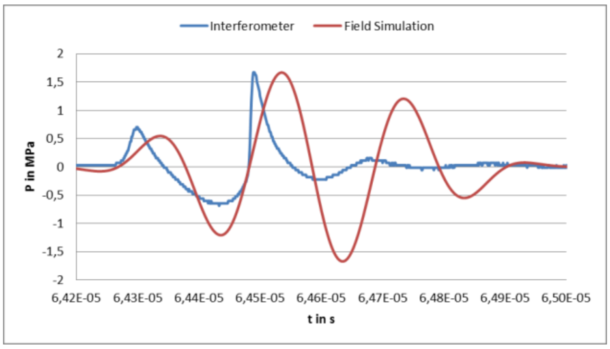

Figure 3: Measurment and simulation of the transducer at 100 V excitation voltage

Special thanks to Dr. Wilkens and the whole team at the acoustic lab of PTB, Braunschweig, for providing us with the chance for the interferometer measurements.

Literature

[1] Jensen, J. A. Field: A Program for Simulating Ultrasound Systems. Medical & Biological Engineering & Computing Volume 34 (1996), 351-353

[2] Jensen, J. A. Calculation of pressure fields from arbitrary shaped, apodized, and excited ultrasound transducers. IEEE Trans. Ultrason., Ferroelec., Freq. Contr 39 (1992), 262-267

[3] Granz, b. The Light Spot Hydrophone – LSHD: A New Level of Precise Ultrasonic Shock Wave Measurement. Thieme, Stuttgart, 2005

[4] Staudenraus, J. Fiber probe hydrophone for ultrasonic and shock-wave measurements in water. Ultrasonics Volume 31 No 4 (1993), 267-273

[5] Jensen, J. A. Linear description of ultrasound imaging systems. Technical University of Denmark, Lyngby Denmark, 2001

[6] Smith, N. et al. comparison of light spot hydrophone and fiber optic probe hydrophone for lithotripter field characterization. AIP Review of Scientific Instruments Volume 83 (2012), 1-8