CALIBRATION OF HYDROPHONE FOR HIGH PRESSURE BY LASER INTERFEROMETRY UP TO 10MPa

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Sensitivity of high frequency hydrophones are vitally important to ensure the safety and proper dose for diagnostic and therapeutic ultrasound equipments. But unfortunately, almost all the hydrophones are calibrated in the low pressure field, usually below MPa, which is much lower in the HIFU field. Since linear property of the hydrophone calibrated in low pressure field can not be assumed ideal in the unlimited pressure range, it's necessary to calibrate the hydrophone in the high pressure field. In this article, hydrophones applied in high pressure field are calibrated by the heterodyne interferometer system, large displacement on the reflecting resistance membrane is measured directly by the interferometer. Experiments showed that the sensitivities of the hydrophone are different at high pressure level, with the highest peak-to-peak pressure near 10 MPa and the expanded uncertainty about 12%.

1. Introduction

High Intensity Focused Ultrasound (HIFU) is a non-invasive therapy technique for the treatment of tumors, which has drawn much attention in the therapeutic ultrasound field [1-2]. The principle of HIFU technique is to focus a large amount of acoustical energy into a small volume by using ultrasonic focusing transducers, which raise the tissue temperature and cause the ablation of tumor cells. For safety consideration in operation and design of the equipments, precise measurement of the spatial and temporal distribution of the HIFU field is vitally important.

The acoustical intensity up to 20 000 W/cm² and the heating rates up to 30 °C/s can occur[3,4], sensors characterizing the HIFU fields should be robust enough to withstand such exposure. The fiber-optic probe hydrophone (FOPH) has a small sensing element, which can reach a higher spatial and temporal resolution[3]. As has been discussed by Samuel and Claudio[5], a special design of metallic coating on the miniature piezo-ceramic sensing element can help minimize nucleation sites for cavitation and provide a level of "blast protection". Compared with the FOPH, a robust needle hydrophone is much cheaper and easier to be available. In this article, experiments were conducted using a robust needle hydrophone to measure the HIFU field.
2. Method

The basic idea for the calibration of the robust needle hydrophone involves the determination of the free field acoustic displacement generated by a focusing transducer at a position in the acoustic field. A thin Polyethylene Terephthalate (PET) membrane (10 μm in thickness) coated with Aluminium is positioned on the surface of water, which reflects the optical beam but moves in sympathy with the acoustic wave[6-8]. In the focal region of the transmitter, the acoustic pressure can be derived from simple linear relationship with the acoustic displacement. Then the pellicle is substituted with the needle hydrophone at the same place and the output voltage of the hydrophone can be measured. The free field sensitivity of the hydrophone can be achieved from the ratio of the output voltage to the free field acoustic pressure. The water tank used in the experiment is a cube made of perspex, which has a side length of 400 mm. The focusing transducer was excited by tone bursts. The length of the pulse duration was set as the function of the frequency to avoid multiple reflections from the water surface. The transducers and the foil positions were adjusted by the outer facilities with displacement resolution better than 10 μm and angular resolution better than 0.02°.

![Figure 1: Schematic diagram of the robust needle hydrophone calibration system based on heterodyne interferometer. BS is the beam splitter, PD is the photo detector, QWP is the quarter-wave plates, MO is the microscope objective and AOM is the acousto-optical modulator (Bragg cell).](image1)

![Figure 2: Picture of the Calibration System.](image2)

To measure the acoustic displacement, a heterodyne interferometer based on Mach-Zehnder arrangement is built. The schematic diagram and experimental arrangement of the robust hydrophone calibration system is shown in Fig. 1 and Fig. 2 respectively. A He-Ne laser is used as the light source. The Bragg cell (MT-80-B30A1-VIS, Photop Suwtech) used in the interferometer can cause
a frequency shift of 80 MHz between the measurement and reference beams. A Si amplified fixed detector (PDA10A, Thorlabs) with bandwidth of 150 MHz is used to detect the carrier signal which is phase modulated by the vibrations of the pellicle. The detected signal is frequency mixed with the signal came from the double channel signal generator, then the carrier signal is filtered by the band-pass filter (NF, FV-628B). The phase carrier signal is then sampled by the data acquisition card (NI, PCI-5124). The signal processing procedure is conducted using Labview as shown in Fig. 3. A much more detailed investigation and uncertainty analysis has been undertaken [8] which identified the demodulation theory and several corrections.

3. Result and discussion

To generate high-intensity focused-ultrasound fields, a homemade focused transducer with 1 MHz centre frequency, 96mm diameter and focal distance of 153 mm was used. The transducer was driven by the 33622A pulse generator (Agilent Technologies, Palo Alto, CA) gated to provide a tone-burst of fifty cycles of a 1 MHz fundamental, which was then connected to a R. F. power amplifier (800A3, AR, Souderton, PA). The pulse repetition frequency used was 100 Hz. Care must be taken that the signals should be recorded without interference from multiple reflections.

![Figure 3: Signal processing procedure in the heterodyne interferometer.](image)

![Figure 4: Calibration Results of the Hydrophone.](image)
The driving voltage varies from 60 Vpp to 160 Vpp, may resulting in a nonlinear acoustic phenomenon. The harmonics of acoustic signal was analyzed by DFT. To analyze the sensitivity of the hydrophone at high acoustic pressure, as an example, the fundamental frequency sensitivity is shown in Fig. 4. Table 1 shows the uncertainty budget of the hydrophone sensitivity. The acoustic pressure was from 3.60 MPa to 9.24 MPa for the fundamental. As shown in Fig. 4, the sensitivity of the hydrophone at 1 MHz is not constant, but decline with the increasing pressure, which proved the linearity of the hydrophone should not be assumed to be ideal.

<table>
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<tr>
<th>Source of Uncertainty</th>
<th>60Vpp</th>
<th>100Vpp</th>
<th>160Vpp</th>
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<tr>
<td>spatial averaging</td>
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<tr>
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<td>1.2</td>
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<tr>
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<td>expanded uncertainty</td>
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<td>12.0</td>
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</table>

4. Conclusion

This paper has presented a preliminary calibration for a robust needle hydrophone used in HIFU field. Experiments showed that, at the fundamental frequency points, sensitivities decline with the increasing pressure up to near 10 MPa, proved that the linearity of the hydrophone in high pressure field can not be supposed ideal. Further experiment and analysis will focus on the calibration of hydrophone for high pressure at the harmonic frequency points and then comparing the acoustical signal recovery in therapeutic ultrasound field by laser signal and by hydrophone signal.

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REFERENCES


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