A New Method of Ultrasonic Hydrophone Calibration
using Wave Propagation Modeling

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Abstract: A new method is presented for hydrophone calibration using the Khokhlov - Zabolotskaya - Kuznetsov (KZK) equation. Simulated and experimental on-axis finite amplitude distortion time waveforms and frequency spectra are compared. The hydrophone calibration up to 100 MHz is estimated for two different hydrophones.

INTRODUCTION

Most commercially available ultrasonic transducers exhibit finite amplitude distortion in water during hydrophone measurements. The frequencies observed due to finite amplitude distortion can easily exceed 10 times the source nominal center frequency. Newly proposed hydrophone calibration specifications suggest sensitivity variations less than ±3 dB from 1/20 to 8 times the source center frequency during finite amplitude distortion measurements (1). Therefore, hydrophone calibration should be available to at least 80 MHz for high frequency diagnostic ultrasound transducers (typically, highest excitation frequency of 10 MHz). If this specification is not met, the misrepresentation of harmonic energy will distort the measured acoustic waveforms and increase the uncertainty in intensity and pressure measurements. Hydrophone calibrations are typically available from 1 to 15 or 20 MHz, only. The proposed technique will use the existing calibration information and extend it up to 100 MHz.

METHOD AND EXPERIMENT

The hydrophone calibration was determined for two hydrophones in the frequency range up to 100 MHz. First, a measured finite amplitude distorted waveform was compared with the corresponding simulated waveform. It was initially assumed that any difference in the frequency content was solely due to the hydrophone spectral characteristics. To facilitate the comparison, the source center frequency was selected to be within the known hydrophone calibration frequency range and the simulated and measured spectral energy were normalized with respect to the source center frequency. The difference between the simulated and measured spectral responses contains desirable information on the hydrophone frequency response from the source center frequency to 100 MHz.

The time-domain algorithm that solves the KZK nonlinear parabolic wave equation was selected for the simulating model. The ability of the model to predict the nonlinearity, diffraction and absorption of focused circular transducers has already been demonstrated in several papers (2-4).

The measurement equipment consisted of a test tank with positioning apparatus, Lecroy 334AL digital oscilloscope, HP 8116A pulser/function generator, Amplifier Research 25A100M2 power amplifier, two 50µm bilaminar membrane hydrophones (from two different vendors) with preamplifiers and with 0.5 and 0.6 mm active element diameters, and a 5 MHz ECHO Ultrasound single element focused circular transducer. The source radius and geometrical focus were determined to be 5.5 mm and 40.0 mm, respectively. Based on these measurements, three dimensionless parameters needed as inputs for the finite difference algorithm that solves the KZK non-linear parabolic wave equation were determined as $G = 8.0$, $A = 2.5E-2$ and $N = 0.47$ (4).

The transducer was excited with a 15 cycle sine wave burst at 5 MHz and with 3 volts peak to peak for the transducer characterization. The geometrical transducer axis was aligned with the gantry axis (and hydrophone) to within 0.7 degrees. The actual axial peak distance, which was expected to be shallower than the geometric focus, was found to be located at 35 mm and the measured waveforms were found to have harmonic energy less than -30 dB from the fundamental. The excitation voltage was then increased to 65 volts to introduce finite amplitude

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RESULTS AND DISCUSSION

The two hydrophone measured waveforms were compared with those generated by the KZK model and the corresponding frequency spectra were calculated using a FFT routine in MATLAB. The resulting finite difference algorithm frequency spectrum was subtracted from both hydrophone frequency spectra at the source center frequency and harmonic frequencies. The spectral information at the source center frequency (5 MHz) was then normalized to the corresponding available hydrophone frequency calibration. The results are illustrated in Figure 1 below. The differences in sensitivity from 20 to 100 MHz between the two hydrophones were determined to be mainly due to differences in their preamplifier design. The origin of the observed “resonances” at 45 and 70 MHz (Figure 1B) with one hydrophone is not yet clearly understood. Neither hydrophone meets the newly proposed calibration specifications for use with high frequency diagnostic ultrasound transducers (1).

**Figure 1.** Frequency spectral characteristics of a 5 MHz transducer determined using two membrane hydrophones (X’s and O’s) vs. simulation (+’s) (left). Two hydrophones (X’s and O’s) simulated calibration vs. manufacturer calibration (solid lines) (right).

CONCLUSIONS

The presented technique used a focused source and wave propagation modeling with the KZK equation to provide the spectral information allowing hydrophone calibration to be determined up to 100 MHz. The calibration results match very well with the available manufacturer calibration data at 10, 15 and 20 MHz, to within specified uncertainties, except for one hydrophone (X) at 20 MHz. The proposed hydrophone calibration method is currently being validated and overall uncertainty of the technique is being determined.

REFERENCES