

RAY TRACE MODELING OF MULTIPATH IN ULTRASOUND POWER MEASUREMENT SYSTEM

Lixue Wu

Institute for National Measurement Standards, National Research Council Canada
1200 Montreal Rd., Ottawa, Ontario, Canada K1A 0R6

1. INTRODUCTION

The measurement of ultrasonic power in liquids (commonly water) is based on the measurement of the radiation force using a gravimetric balance. A schematic representation of the INMS ultrasound power measurement system is shown in Fig. 1. A conical target submerged in water is suspended using thin wires from a small hook at the bottom of an electronic balance. The transducer with its active surface submerged in water is positioned coaxially above the target. The radiation force generated by the transducer that impinges on the target is measured by the electronic balance [1].

Additional lateral absorbers that line the wall of the water tank reduce, but do not completely eliminate, reflections at the walls of the tank. In the above arrangement, there are two assumptions: 1) the ultrasonic beam is a plane wave; and 2) the target is large enough that the entire ultrasonic beam is intercepted. The acoustic power radiated from the transducer can be then related to the radiation force measured by the electronic balance [2].

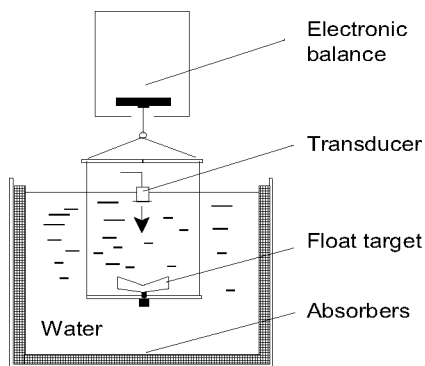


Fig. 1. Schematic diagram of the ultrasound power measurement system.

Multipath, the propagation phenomenon by which ultrasound waves reach the target by two or more paths, exists in such a system. The main causes of multipath are

reflections from the imperfect absorbers at the tank walls and from the water surface. In ultrasound power measurements, multipath can cause constructive and destructive interference and affect the quality of measurements. In this paper a ray tracing ultrasound model is described that calculates the ultrasound pressure at some point in a water tank remote from an ultrasound source. The method parallels the process of geometric optics and assumes constant ultrasound speed in water. The discussion of an experiment results shows the validation of the ray trace modeling method. An algorithm is also presented that finds the optimal measurement settings (water depth and target distance) for an existing ultrasound power measurement system to minimize the effect of multipath.

2. MULTIPATH MODELING

2.1 Assumptions

The temperature variations in water are less than 0.05 °C under laboratory conditions. These variations result in sound speed variations less than 168 ppm. With such a small value one can assume constant sound speed in water. Thus, sound propagation takes place in straight line paths. The wavelength of the ultrasound radiation is much smaller than the target and absorbers so that no scattering occurs in water. With these assumptions, a ray trace model that parallels the process of geometric optics can be used to model the ultrasound propagation [3]. Shown in Fig. 2 is an illustration of the ray traces that occur for different water levels. Raising the water level can prevent the reflected sound wave from reaching the target.

2.2 Ultrasound source images

The formation of multiple images of an ultrasound source due to the reflecting surfaces can further simplify the calculation. The source images due to the reflecting target for two different transducer positions are illustrated in Fig. 3. Only half of the images are shown because of cylindrical symmetry of the measurement system. When the distance of the target from the transducer increases, the ultrasound beam begins to diverge as shown by the dashed lines in Fig. 3. Source images due to secondary reflections from the target are not considered because of the high absorption of the material from which the absorbers are made.

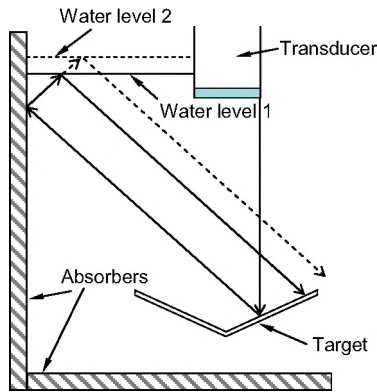


Fig. 2. An illustration of ray traces for different water levels.

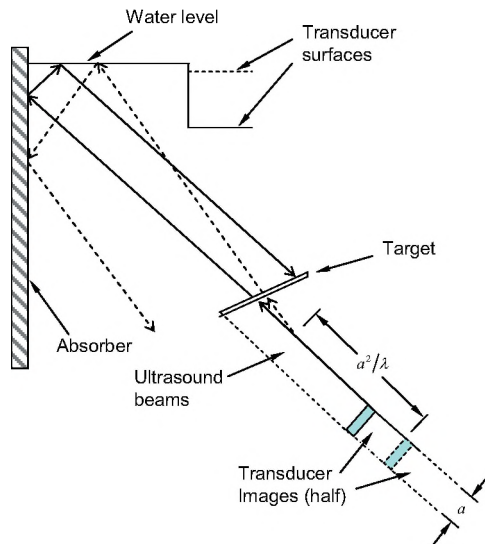


Fig. 3. An illustration of sound source images by the reflecting target for different transducer positions.

2.3 Ultrasound pressure calculation

The returning beam is always parallel to the incident beam as shown in Fig. 3 because of the geometry of reflection surfaces (the water level is perpendicular to absorber). Varying the water level and the transducer position may shift the returning beam apart from the incident beam, preventing it from reaching the target. When the returning beam does impinge on the target the ray trace model can calculate the ultrasound pressure of the returning reflections on the target. The most recent edition of international standard IEC 61161:2006-12 [2] requires that returning reflections do not contribute to more than 1 % of the overall measured power.

3. OPTIMIZATION ALGORITHM

An optimum water level and transducer position that minimize the effect of multipath on the measured ultrasound power can be found. An optimization algorithm has been developed based on the ray trace model. For a given water level and transducer position, the algorithm can calculate the additional radiation force due to the returning beam intercepted by the target. An exhaustive search of all possible water levels and transducer positions can find the optimal setting. The algorithm assumes a perfect disc transducer with uniform velocity movement over its surface. Water attenuation, reflection coefficients of the absorber, and transducer beam shape (depending on whether the target is within near zone or far zone) are incorporated into the algorithm.

4. VERIFICATION

An experiment was setup at 1 MHz for verifying: 1) transducer beam shape; 2) incident beam (reflections from the target) shape; 3) returning beam (reflections from absorber or water surface) shape and 4) ultrasound pressure of returning reflections at the target. A broadband needle hydrophone (Mediscan, No. 82), diameter = 1.25 mm, with a wide angular response was added to the existing ultrasound power measurement system. A tone-burst signal was fed to the transducer so that the direct waves and reflections can be distinguished by their different arrival times at the hydrophone. The hydrophone outputs were recorded by a digital oscilloscope for comparison with those calculated by the ray trace model.

5. DISCUSSION

The experimental data show that the measured beam shapes are within ± 5 mm of those calculated by the ray trace model. Considering the spatial resolution of the hydrophone and the accuracy of its positioning system (no 3D translation table), this is good agreement. The measured sound pressures of returning reflections at the target do not agree well with those calculated by the model. This is due to the constructive and destructive interference of the secondary reflection from the target. If the hydrophone is placed 2 cm above the target, the secondary reflection from the target can then be separated. In this case, the measured ultrasound pressures of returning reflections are within ± 14 % of those calculated by the model.

REFERENCES

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