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A Reduction Method of Reflected Waves for Investigation of Sound Source Location

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Abstract: When the extracorporeal shock wave lithotriptor is operated, sounds can be heard. Then that might be a question about the location where the sounds come from. For the purpose of investigating the fact, we identify the location of the sounds radiated using one hydrophone. In order to carry out the experiment, it is needed to obtain direct waves from objects. Therefore, we present an experimental method to reduce reflected waves for obtaining direct waves only. The experimental results show the amplitude of waves can be attenuated about 28dB due to a silicon rubber plate of 8.5mm attached at the bottom. This is a quantified result that can expect to obtain the direct waves using the proposed method. Then, we carried out the experiment for the sound source location. From the experimental results, we can undoubtedly present a fact that the sounds are radiated from the objects to be shot due to shock waves.

Key words: ESWL, Reflected wave, Sounds radiated, Direct wave, Acoustic impedance, Sound location

INTRODUCTION

Underwater shock wave for medical treatment has a history of fifty years. The first trial is to break a bladder stone with shock waves generated from electrical discharge by Eutokin[1] in 1950. It has been studied that the external energies to be concentrated broke an object in a living body since 1958. In 1971, Heusler and Kiefer[2] proved a fact that shock waves with high energy can break objects in a body non-invasively. From 1974, Schmidt and Chaussy[3] had experimented in the body of animals. The results of the experiments become a motive to operate with the same method into a human body. The first device for breaking a calculus was made in September 1979. In February 1980, Chaussy[4] obtained the result to break a stone of 1.5cm thoroughly in a right kidney of a patient.

As the study to use underwater shock waves progressed, the energy sources to generate shock waves and the focusing methods of shock waves were studied very much.

Then several kinds of extracorporeal shock wave lithotriptor (ESWL) were developed. The ESWL being considered in this paper produces a shock wave with piezoelectirc elements which can generate ultrasonic waves respectively[5].

Now the piezoelectric ESWL seems the most famous because the piezoelectric ESWL can break a stone into fine pieces. The therapy of calculus is not just breaking stones in a body. The most important issue is to eliminate the stones from the body.

Therefore a criterion to evaluate effectiveness of that is depend on the ability to break a stone into small pieces. The piezoelectric ESWL can break a stone into the sizes to be eliminated outside of the body. There have been many studies for the piezoelectric ESWL such as analysis of radiated sounds[6, 7], relation with cavitation[8-13], etc.

In this paper, we investigate where the sounds are radiated from for the purpose of establishing a fact that the sounds are radiated from the objects to be shot by shock waves. For the experiments, we propose a method to remove reflected signals in a water tank. By using the proposed method, we can reduce the noise effect and obtain direct signals to have informations related to the objects to be shot by shock waves. We confirm the effect of proposed method experimentally and present the experimental results.

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PROPOSITION OF NOISE REMOVAL METHOD FOR MEASURING DIRECT SIGNALS

Measurements of Focal Region

A piezoelectric shock wave generator in this paper is a device for a performance test produced at Toshiba corporation in Japan. The difference between the test device and a real one is the peak pressure at the focal point. The positive peak pressure of this test device is 82MPa and this value is 82% of a device on the market. The focal region is located at where is about 25cm distant from the center of the vibrator. The pressure of the vibrator is controlled by a power amplifier.

Figure 1 shows the basic configuration for the piezoelectric ESWL experiments. As shown in Fig. 1, the vibrator is set up in the direction of the bottom and a pulse generator is used to control the interval among shock waves. The signals radiated are measured by a digital storage oscilloscope and then analyzed by an fast Fourier Transform (FFT) analyzer. A three-axis stage controlled mechanically is used for changing the location of objects. It can move the location of objects with the level of 0.05mm.

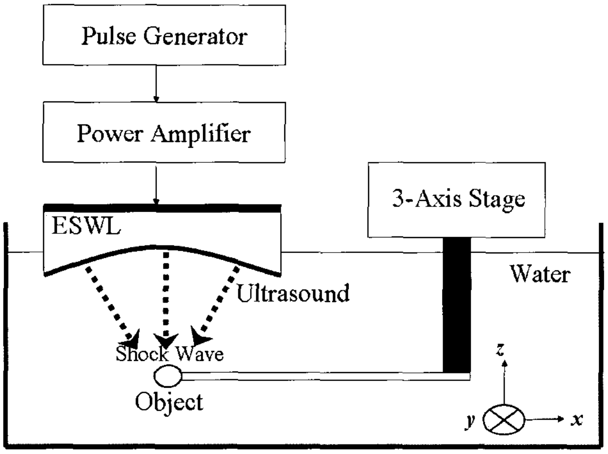

Fig. 1. The basic configuration for the experiments.

To begin with, the amplitudes of the shock waves around the geometrical focus are investigated to confirm the focal region. In this experiment, the shock waves are measured by a hydrophone which is iron-covered specially for measuring shock waves. Figure 2 shows the experimental results measured by the special hydrophone and represents the amplitude of the focal region on three-axis. On x and y-axis horizontal with the vibrator, it is found that the pressure is strong just at small focal region like a point. The region having the pressure over 80% on x and y-axis is about 0.25cm and 0.15cm respectively. On z-axis that the shock waves are progressing, we can observe the region having the pressure over 80% is about 1.30cm. From the measurement results, it can be concluded that the length of the focal region along z-axis is much longer than that along another axis and it is about one centimeter to the direction which the shock waves are progressing.

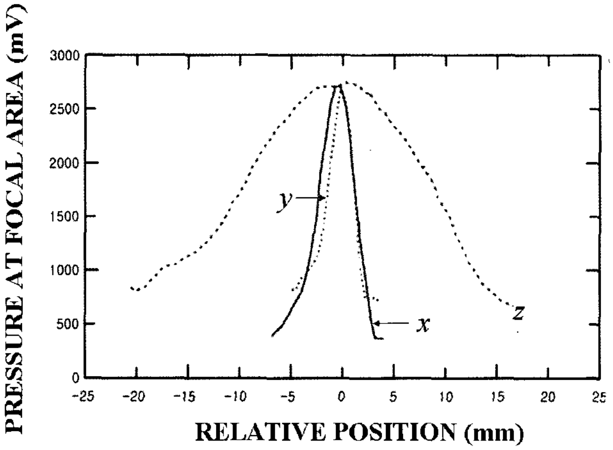

Fig. 2. The focal region formed in each direction.

Reduction of Reflected Sounds for Observing Direct Sounds

To investigate a sound source, we need to receive the sounds more directly. Accordingly, it is desirable to measure the sounds in water. The measurement of sounds plays an important part in the study about radiated sounds. Radiated sound means that the sounds are generated from an object to be shot by shock waves. The most correct data can be obtained if only direct sounds can be received from an object. However, the reflected sounds have a harmful effect on the analysis of the radiated sounds because the size of a water tank is limited and many waves are reflected from the surface, the side and the bottom of the water tank. Generally, it is difficult to distinguish the direct sounds from the reflected sounds and to observe the power spectra of the radiated sounds.

The absorption material is attached to the water tank for removing the reflected sounds. The experiments are carried out for examining the effect of the absorption material. The radiated sounds are analyzed with a digital storage oscilloscope to observe where the magnitude of the reflected sounds are bigger. In this experiment, we investigate the traveling time from the object to the hydrophone and the distance among the positions of a hydrophone. The experimental results represent that the reflected sounds from the bottom are undoubtedly bigger than ones from the other places. Figure 3 shows a typical waveform of the radiated sounds and the wave at the back having bigger magnitude is the wave reflected from the bottom.

In order to remove the reflected waves from the bottom, we make a plan to attach the absorption material into the water tank. The acoustic impedance of the absorption material almost coincides with that of water. And the absorption material has characteristics not to reflect and to attenuate the waves. The silicon rubber (KE12) used as the absorption material has the density ρ_s =1640kg/m^3 and the sound velocity c_s=933.8m/s. And the acoustic impedance Z_s and the reflection coefficient R of the absorption material is given by[14]

$$Z_s = \rho_s c_s$$
$$R = \frac{\rho_s c_s - \rho_w c_w}{\rho_w c_w + \rho_s c_s} \qquad (1)$$

where the density of water ρ_w=1000kg/m^3 and the sound velocity of water (at 25° C) c_w =1496.74m/s. In our case, the absorption material has Z_s=1.53kg/m^{2}s and R=0.01. The silicon rubber selected has good characteristics as the absorption material because both of the acoustic impedances are almost similar and the reflection coefficient is sufficiently small.

The experiment is carried out to evaluate the attenuation of the reflected waves when the silicon rubber is used as the absorption material. A plate (thickness 8.5mm) is produced with the absorption material for this experiment.

First, the shock wave through the focal point traveling into the bottom is measured by a hydrophone at the bottom. Next, a silicon rubber plate is set up below the focal region and the shock wave passing through the plate is measured at the same position. Then we compare the wave measured without and with the silicon rubber plate and measure the quantity attenuated due to the silicon rubber plate.

From the experimental results, the amplitude of the wave is attenuated about 14dB due to a silicon rubber plate of 8.5mm. Estimating the case that the same plate is attached to the bottom, we can expect the attenuated quantity of 28dB because the traveling waves return from the bottom. Therefore we attach the silicon rubber plate of 10mm at the bottom to expect the attenuated quantity over 30dB. Figure 5 shows the waveform of the radiated sounds measured after attaching the silicon rubber into the water tank. As compared with the wave in Fig. 3, it can be confirmed that the reflected wave is much attenuated in Fig. 5.

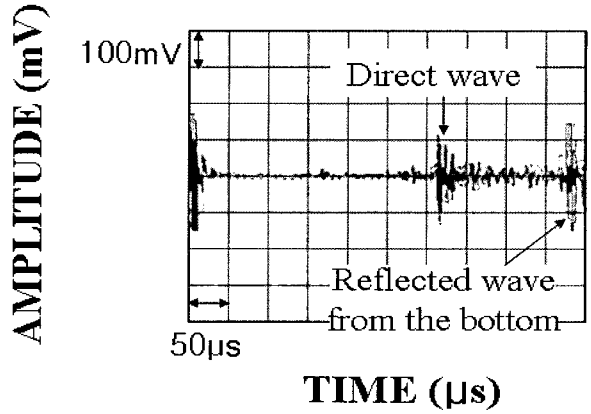

Fig. 3. A typical waveform of the radiated sounds measured before attaching the absorption material.

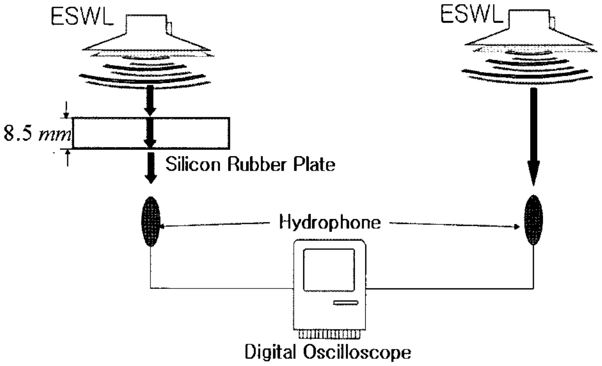

Fig. 4. The method for the experiment to evaluate the efficacy of the absorption material.

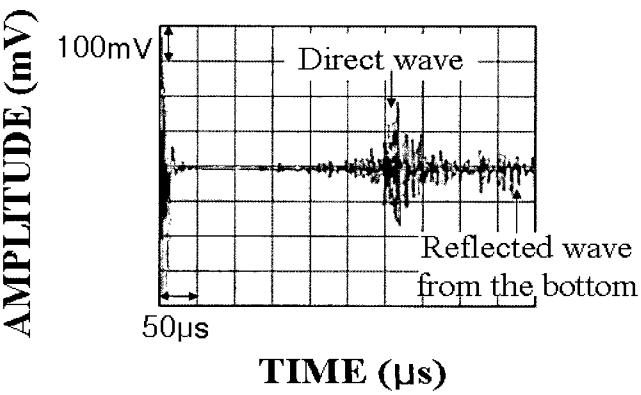

Fig. 5. A typical waveform of the radiated sounds measured after attaching the absorption material.

IDENTIFICATION OF SOUND LOCATION

The radiated sound means that the sounds are generated from an object to be shot by shock waves as indicated above. That might be a question about the location where the sounds radiated are generated from. There might be a question about the sound source location where the sounds radiated are generated. Really, sounds are heard in the situation without objects at focal region. However, by listening the sounds radiated from shock wave disintegration of the stone during treatment, a skilled operator can determine whether the stone is hit by the shock wave or not. This is the conception of the study to analyze the radiated sounds due to the piezoelectric ESWL for obtaining the information about the object to be shot. Thus, it is needed to confirm the fact that the radiated sounds are generated from the object. Therefore, we carry out the experiment to identify the location where the sounds radiated are generated, or where the sound source is.

The method using sensor array[15-17] is applied for identifying the location of the sounds radiated, Figure 6 shows the configuration of the experiment. The sounds are received by not sensor array but a sensor, or a hydrophone. H_1, H_2, and H_3 are the hydrophone positions to be changed and D_1 and D_2 are the distances between the hydrophone positions depicted in Fig. 6. The distances between the hydrophone positions are selected to a constant distance D. The positions of a hydrophone are moved to measure the radiated sounds at each position. Then the location of a sound source is calculated and estimated from the measurement value.

The equations to estimate the sound source are given by

$$R_s = \frac{D_1\left[1-\left(\frac{C\tau_{21}}{D_1}\right)^2\right]+D_2\left[1-\left(\frac{C\tau_{32}}{D_2}\right)^2\right]}{2\left(\frac{C\tau_{32}}{D_2}-\frac{C\tau_{21}}{D_1}\right)} = \frac{1}{\tau_{32}-\tau_{21}}\left[\frac{D}{C}-\frac{C}{2}(\tau_{32}^2+\tau_{21}^2)\right] \quad (2)$$

$$\Theta_s = \cos^{-1}\left[\frac{D_2^2-2R_sC\tau_{32}-(C\ \tau_{21}^2)}{2R_sD_2}\right] = \cos^{-1}\left[\frac{D^2-2R_sC\tau_{32}-(C\ \tau_{21}^2)}{2R_sD}\right] \quad (3)$$

where τ_{21} is the delay time between H_1 and H_2, τ_{32} is the delay time between H_2 and H_3, and C is the sound velocity. Ultimately the location of the sound source is decided by R_s and Θ_s where R_s means the distance from 2nd hydrophone position H_2 to the object and Θ_s is the bearing.

In the experiment, the theoretical values are calculated by D = 10cm and C = 1500m/s. A bronze bar is employed as an object and the length and the radius of cross section is 6cm and 0.5cm, respectively. The peak pressure of the device, 82MPa, is used to hit the object. The object shot by the shock waves is located at the position that has the distance 18.0cm and the bearing 0.63π. Figure 7 shows the waveform measured at each of the hydrophone positions. From these results, the measurement values τ_{21} and τ_{32} are 20μs and 45μs, respectively. By substituting the delay time values to Eqs. (2) and (3), we can obtain the values R_s = 19.4cm and Θ_s = 0.64π, which almost coincide with the true values 18.0cm and 0.63π. Therefore, it is concluded that the source of the sounds radiated is located from the object at the focal region.

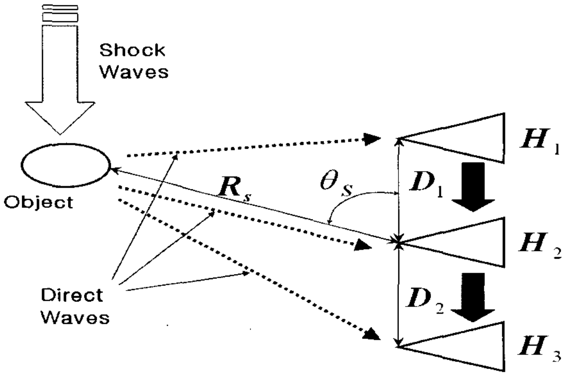

Fig. 6. The experimental configuration for the identification of the sound source.

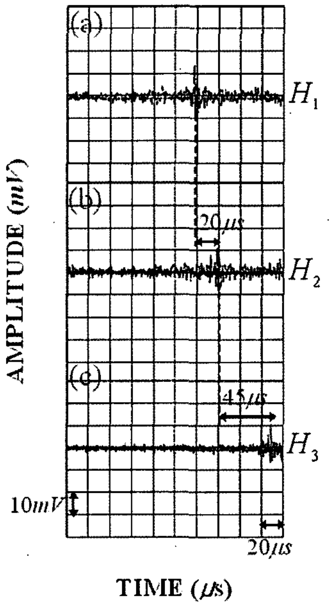

Fig. 7. The sounds measured by a hydrophone at each position.

RESULTS AND DISCUSSION

In this paper, the location of the sound source radiated when the piezoeletric ESWL is operated can be identified clearly using a hydrophone. We believe that this fact can solve a question about the sound source location where the sounds radiated are generated.

And the study of the radiated sounds has difficulties because the strong reflected waves appear in a water tank. We also proposed a method using the silicon rubber as the absorption material to remove the reflected waves. The efficacy of this method was confirmed experimentally.

From these results, we conclude that the radiated sounds during treatment due to the piezoelectric ESWL can be a important clue to estimate the breaking process. Because we confirmed the fact that the radiated sounds are generated from the object to be shot by the piezoelectric ESWL.

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