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Power Difference in Spectrum of Sound Radiation before and after Break of Phantom by Piezoelectric Extracorporeal Shock Wave Lithotriptor

Hiroshi KANAI, Yun-Seok JANG, Noriyoshi CHUBACHI and Yoshikatsu TANAHASHI[1]
Department of Electrical Engineering, Faculty of Engineering, Tohoku University,
Aramaki-aza-Aoba, Sendai 980
[1] *Division of Urology, Tohoku Kohsai Hospital,*
Kokubun-cho, Sendai 980

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This paper investigates the difference in the spectrum of sound radiated before and after the break of a phantom at a focal point of the piezoelectric extracorporeal shock wave lithotriptor (ESWL) in order to identify the break time or to examine whether a calculus exists exactly at the focal point or not. From the preliminary experiments using a piece of chalk as a phantom of a calculus to measure the sound radiated when impact is applied to the chalk by an impact hammer, it is found that the bending vibration component of the vibration is exhibited in the spectrum of sound. However, for small-sized chalk shorter than 3 cm, the peak frequency of the bending vibration is higher than 20 kHz. From the experiments using a piezoeletric ESWL, it is found that there is clear difference in the power spectra among the sound radiated before the break, that radiated just after the break in the breaking process, and that radiated when the chalk does not exist at the focal point of the ESWL. These characteristics will be effective for the examination of the existence of the calculus at the focal point.

KEYWORDS: piezoelectric ESWL, calculus, break time, bending vibration, radiated sound

1. Introduction

Recently, the effectiveness of extracorporeal shock wave lithotriptor (ESWL) for the therapy of calculus has been generally known in the field of urology. At the same time, however, the following problems have arisen; it is necessary to prevent shooting of normal tissue or bone, to identify the break time of the object, and to examine the existence of the calculus at the focal point of the ESWL.[1)] Indeed the position and size of a calculus can be estimated from X-ray images before the operation and its position can be roughly monitored by ultrasonic imaging during the operation, but it is sometimes difficult to distinguish calculus fragments from its surrounding structures.

By listening to secondary sounds[2,3)] radiated from shock wave disintegration of the calculus during treatment, a skilled operator can determine whether the calculus is hit by the shock wave or not. Thus, some work was performed to develop an automatic method for classifying these secondary sounds and to utilize a computer to provide an immediate indication of the success of treatment based on spectrum analysis of the radiated secondary sounds.[3,4)] However, to date, there are not papers which describe the change in the spectra of sounds radiated during the breaking process of a calculus.

In this paper, therefore, we analyze the spectra of sounds radiated during the breaking process of a phantom in the ESWL. In our experiments itself, a piece of chalk is employed as the phantom instead of the calculus itself because the acoustic impedance of the chalk almost coincides with that of the calculus. From the experimental results in §3, it is found that the power spectra of the radiated sounds have a close relationship to the break and the existence of the chalk at the focal point.

2. Preliminary Experiments for Bending Vibration of Chalk

To begin with, three pieces of chalk (6.2 cm, 4.5 cm, and 3 cm in length) are struck by an impact hammer in order to observe the sounds radiated from them. Figure 1 shows the sounds measured by a microphone and their power spectra. For the chalk pieces of 6.2 cm and 4.5 cm in length shown in Figs. 1(1-b) and (2-b), the peak frequencies are 4.6 kHz and 9.1 kHz, respectively, which almost coincide with the resonance frequency f_1 of the bending vibration theoretically given by[5)]

$$f_n = \frac{a\lambda_n^2}{4\pi l^2} v_l, \quad (n = 1, 2, \cdots) \tag{1}$$

where $\lambda_1 = 4.73, \lambda_2 = 7.85, \lambda_3 = 10.99, \cdots$. l is length, a is radius of cross section, and v_l is the velocity of the longitudinal wave of the object. In our case, the chalk has $a = 0.50$ cm and $v_l = 2.1 \times 10^2$ m/s. Thus, for the chalk pieces of 6.2 cm and 4.5 cm in length

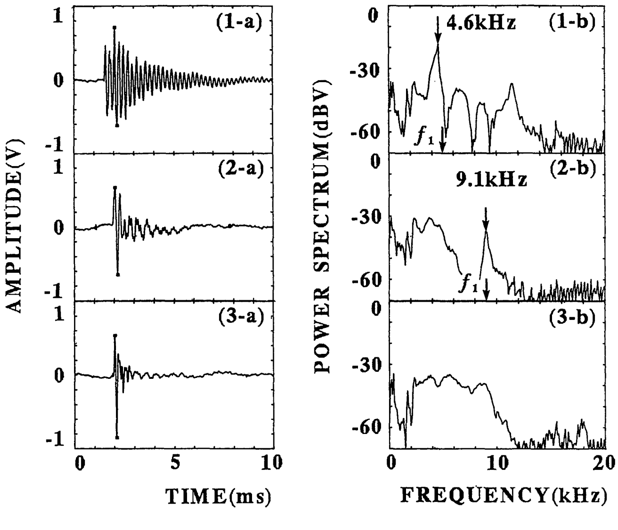

Fig. 1. Sounds radiated when impact is applied to chalk by an impact hammer and their power spectra. The lengths of the chalk are (1) 6.2 cm, (2) 4.5 cm, and (3) 3 cm. (a) Waveform and (b) power spectrum.

(l), the frequency(f_1) values caculated using eq. (1) are 4.9 kHz and 9.2 kHz, respectively. For chalk of 3 cm in length, however, the theoretical value of f_1 calculated using eq. (1) is 20.8 kHz, and a peak is not observed in the resultant power spectrum of Fig. 1(3-b) because it lies beyond the audio frequency range of 0–20 kHz.

Thus, for chalk shorter than 3 cm, which corresponds to the small-sized calculus, the frequency peak due to bending vibration appears in the frequency range higher than 20 kHz.

3. Experiments Using Piezoelectric ESWL

Next, sounds from the breaking process of a piece of chalk in the piezoelectric ESWL (EDAP Corp.: LT-01)$^{6)}$ are analyzed. Figure 2 shows the configuration of the equipment and the phantom used in the experiments. The employed chalk is 6.2 cm in length, as shown in Fig. 2(b). The chalk is held by two rubber bands on the square metal frame of the fixing tool so that the broken pieces of chalk are kept in their initial position. Shock waves are applied to the chalk at the focal point of the ESWL until the chalk is broken. During the breaking process, the output signal of the microphone from the sample is recorded by a digital audio tape (DAT) recorder and then analyzed by an fast Fourier transform (FFT) analyzer.

4. Results and Discussion

Figure 3 shows a photograph of the chalk employed in the experiments of §3. After 630 shots of shock waves in the ESWL, the center part of the chalk around the focal point was broken, as shown in Fig. 3(b).

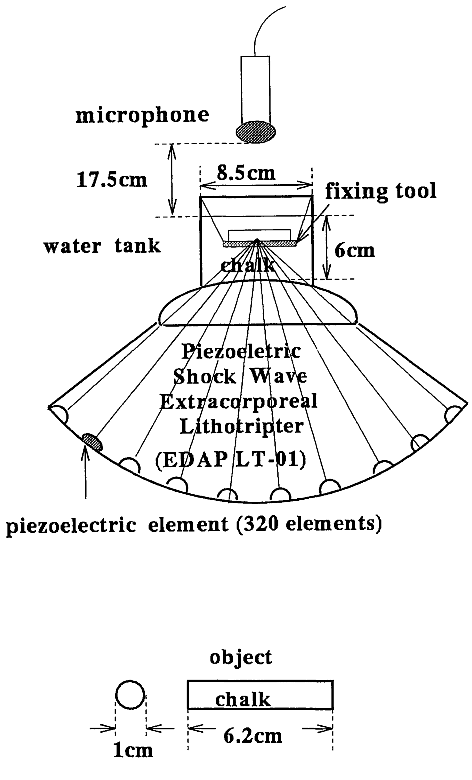

Fig. 2. (a) The configuration of the microphone and chalk in the piezoelectric ESWL and (b) the sample employed in our experiments.

Figure 4 shows the sound signals received by the microphone and the spectrum in each stage of the breaking process of the chalk of 6.2 cm in length. Figure 4(a) shows the sound and its power spectrum in the case where there is only water at the focal region of the ESWL, and this power spectrum is also shown by the dotted line in the power spectra of sounds radiated when the chalk at the focal region is shot, as shown in Figs. 4(b)–4(f). In these power spectra of the breaking process, there is the clear change of the power spectrum $P(f)$, at least in the fre-

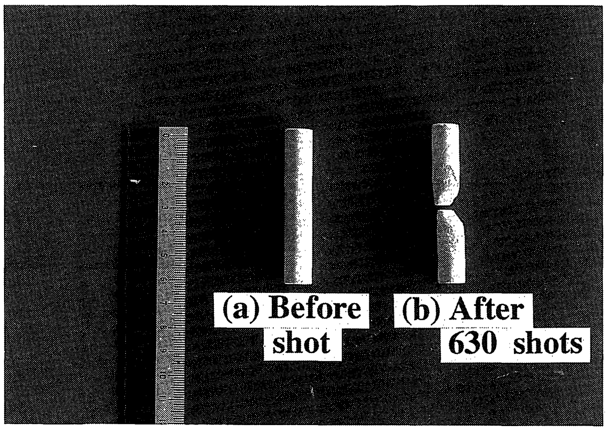

Fig. 3. The photograph shows (a) the original chalk and (b) the broken chalk after 630 shots in the experiments by the piezoelectric ESWL.

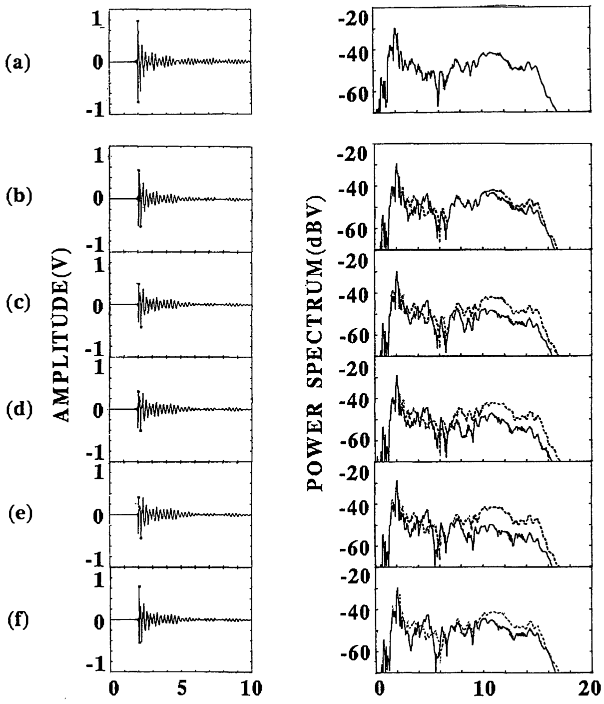

Fig. 4. Sound and its power spectrum for each stage of the breaking process of chalk by the piezoelectric ESWL in Fig. 3. The dotted line in the spectrum of each stage shows the power spectrum in the case where there is only water at the focal region of the ESWL. (a) For the case where there is only water at the focal region of the ESWL. For the case when the chalk is being shot by the ESWL, (b) just after attaining the desired power, (c) after 300 shots, (d) after 560 shots, (e) just before the break and (f) just after the break.

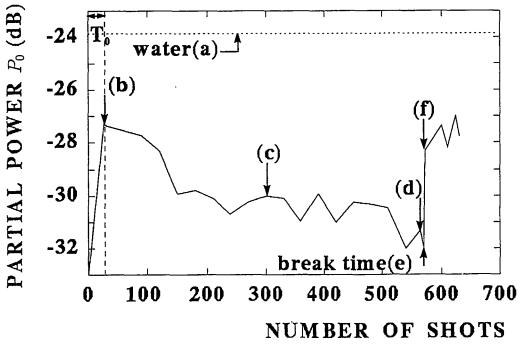

Fig. 5. The partial power P_0 of the sound radiated in the frequency range from 8 kHz to 16 kHz during the breaking process of Fig. 4. The dotted line shows the power P_0 for the case where there is only water at the focal region of the ESWL. The period which is necessary to attain the desired power is represented by T_0. Each sampling time of (a)–(f) coincides with that of (a)–(f) in Fig. 4, respectively.

quency range from 8 kHz to 16 kHz.

Figure 5 shows the partial power $P_0 = \int P(f)df$ for the fresquency range of 8 kHz to 16 kHz in each power spectrum of the sound radiated from the breaking process in Fig. 4. The sampling time of each sound in Figs. 4(a)–4(f) is denoted by (a)–(f) in Fig. 5. In this figure, there is an evident increase of the partial power of sounds radiated just after the break of the chalk at the point (f).

In our experiments, the length of the chalk is about 6.2 cm before and after the break and its corresponding peak frequency is 4.6 kHz, as shown in Fig. 1(1-b). Thus, the frequency range from 8 kHz to 16 kHz, where the evident change appears, does not correspond to the frequency of the bending vibration.

5. Conclusions

This paper describes the experimental results obtained by analyzing the sounds radiated from the sample at the focal point before and after the break in the piezoelectric ESWL. From the preliminary experiments in §2, the component of the bending vibration is exhibited in the power spectrum of the sound radiated from the long chalk. However, for the chalk shorter than 3 cm, the peak frequency is more than 20 kHz, which could not be easily detected by a conventional microphone. From the experiments described in §3 and 4, there is a clear change in the partial power around 10 kHz during the breaking process of the chalk, which, to our knowledge, has not been reported yet. The partial power of the sound increases markedly especially just after the break. However, these frequency components do not correspond to the bending vibration. Thus, this power change may be due to the intensity change of the wave which passes through the focal region in the ESWL. Therefore, the results in Figs. 4 and 5 will be applied to the identification of the break time and the examination of the existence of the calculus in the focal point of the ESWL.

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