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A Basic Study on Nondestructive Evaluation of Potatoes Using Ultrasound

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This paper presents the acoustic properties of potatoes measured by the pulse transmission method with longitudinal ultrasonic waves in a frequency range of 50 kHz to 1 MHz. The average ultrasonic velocity has been measured to be 824 m/s at 100 kHz and the attenuation coefficient is approximately proportional to $f^{1.4}$, where f is frequency. The attenuation for defective potatoes is measured to be much higher than that for normal ones. Therefore, it is suggested that defective potatoes can be detected by attenuation measurements of longitudinal ultrasonic waves.

KEYWORDS: longitudinal ultrasonic wave, acoustic property, potato, defect, ultrasonic velocity, attenuation

§1. Introduction

Ultrasonic measurement techniques for material evaluation have recently been introduced for use in various agricultural products to quantitatively evaluate maturity or to nondestructively detect internal defects.[1,2] Common defects in tubers are a hollow heart, brown rot and black scurf as shown in Fig. 1.[3] These defects can cause serious problems during various stages at the processing plant. Thus, development of a method of detecting defective potatoes nondestructively has been desired. In this paper we report measurement of the acoustic properties of potatoes using longitudinal ultrasonic waves in order to obtain basic data for development of a nondestructive evaluation system for this vegetable.

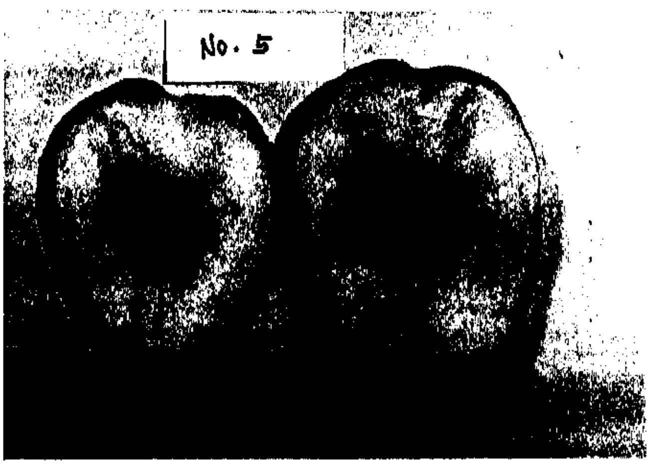

Fig. 1. Photograph of a defective potato with hollow heart.

§2. Acoustic Properties of Potatoes

A mature tuber consists of three structural tissues: the periderm, the cortex, and the pith which occupies the major portion of the potato tuber. In this study, the velocity and attenuation of longitudinal ultrasonic waves in the pith were measured by the pulse transmission method. The species of potatoes used in the experiments is "Wasesiro", which is a promising rareripe potato introduced into the food processing industry about 15 years ago.[4]

Figure 2 shows the measurement system used. A transmitting transducer is excited by RF burst pulses with a maximum peak-to-peak voltage, V_{p-p} of 70 V. These are obtained by gating a sinusoidal wave generated by a signal generator: Longitudinal ultrasonic pulses are radiated into the potato specimen which is inserted between the transmitting and receiving transducers as shown in Fig. 2. The ultrasonic waves transmitted through the specimen are transformed into electric signals by the receiving transducer which has the same specifications as the transmitting one. The signals are gated and then amplified to suppress spurious signals. The resultant signals and their power spectra are obtained using a digital oscilloscope and a spectrum analyzer. The signals, the power spectra, and the measured values of water temperature are transferred to a personal computer via a GPIB interface for the processing of various data.

The ultrasonic velocities are determined by the relation

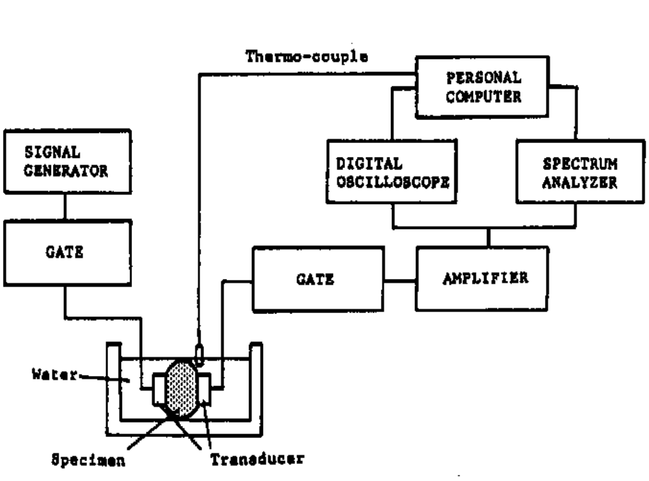

Fig. 2. Block diagram of measurement system used in the experiments.

between the time required for transmission and the distance between the two transducers. The time required for transmission is measured by the lag time between the signal transmitted through the specimen and a reference signal. The reference signal is obtained by placing the two transducers in contact with each other. Both signals are sent to the digital oscilloscope and the transmission time is measured with an accuracy of ±5 ns. The distance between the transducers is equal to the thickness of the specimen, which is measured by vernier calipers.

The attenuation coefficient of a specimen is obtained from the difference of the power spectra between the signal transmitted through the specimens and the signal transmitted through water without any specimen. The attenuation in water, which is temperature dependent, is determined by a method described elsewhere.[5] Frequency dependence of the attenuation between 50 kHz and 1 MHz is measured using three pairs of transducers with center frequencies of 50 kHz, 100 kHz, and 500 kHz, respectively.

A typical waveform and power spectrum are shown in Figs. 3(a) and 3(b), respectively. In these figures, the "Tx. PULSE" shows the reference pulse obtained with the two transducers in contact with each other. The "WATER" and "NORMAL" signals correspond to the waveform and power spectrum of a longitudinal wave pulse transmitted through water and through a parallel cut specimen, respectively. In each case, the distance between transducers is 4 cm. The average value and the standard deviation of the measured ultrasonic velocities of 20 normal fresh potatoes were determined to be 824 m/s and 112 m/s, respectively. As can be seen, the velocity scatter is quite large.

Figure 4 shows the frequency dependence of the attenuation coefficients obtained from the 20 normal fresh potatoes, and the coefficients are found approximately proportional to $f^{1.4}$, where f is the frequency.

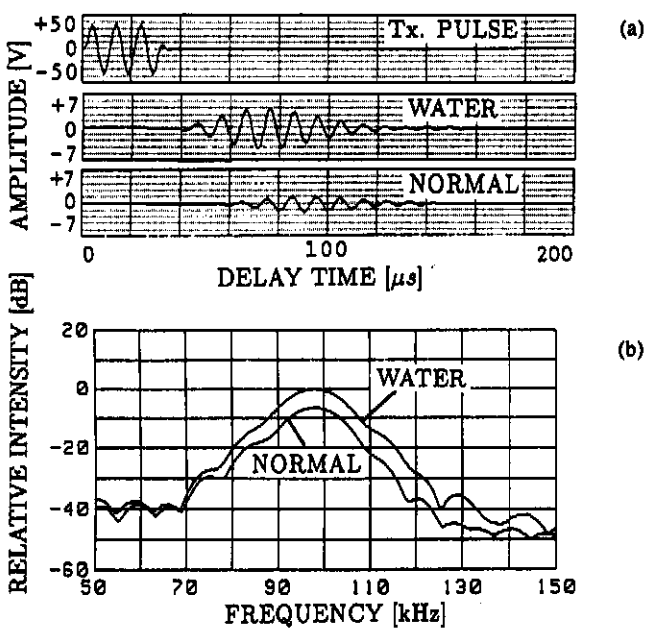

Fig. 3. The exciting pulse and received pulse which are transmitted 40 mm through water and a potato specimen, (a), and their power spectra, (b).

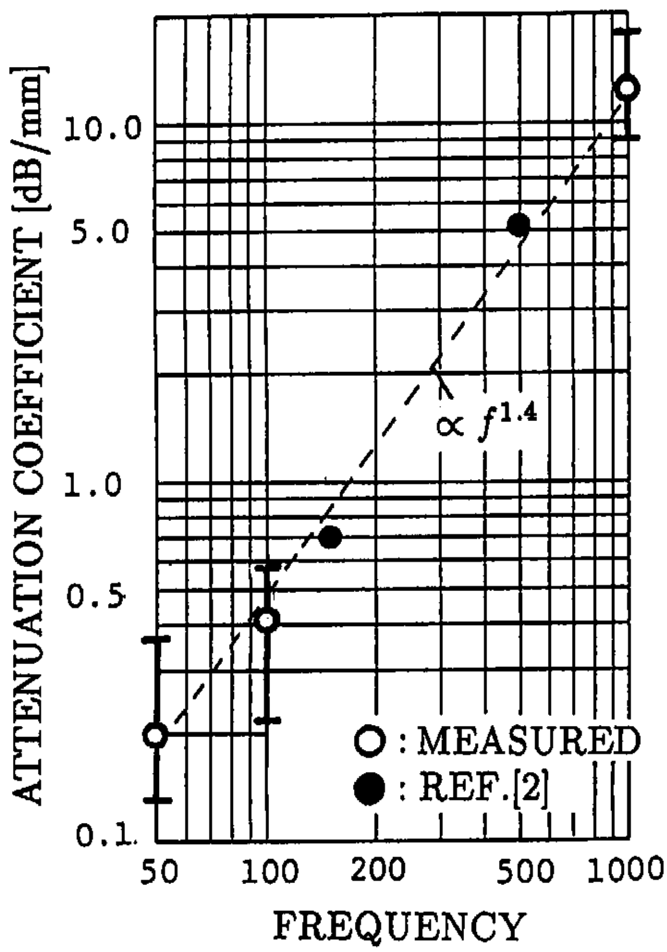

Fig. 4. Frequency dependence of attenuation coefficients for potatoes.

§3. Detection of Defective Potatoes

A hollow heart appears in a potatoes a pore as shown in Fig. 1. In order to compare attenuation properties between a defective tuber and a normal one, a typically received signal of 100 kHz pulse and its power spectrum measured for a defective tuber with a hollow heart are demonstrated in Figs. 5(a) and 5(b), respectively. Figure 5(c) shows the attenuation values obtained from 14 potatoes including 3 defective ones. The distance between transducers is 4 cm; the horizontal axis indicates the specimen number. The attenuation of defective potatoes with pores is larger than that of normal ones by more than 12 dB at 100 kHz when the transmission length is 4 cm.

Figure 6 shows the results of attenuation measurement for 50 non-cut specimens inserted between the transducers set 7 cm apart. The size of the potatoes measured ranged from 4.5 cm to 6.5 cm. The attenuation measured in defective potatoes is higher than that of normal ones. Thus, potatoes which are defective can be identified by measuring the attenuation and comparing it with an appropriate threshold level to be determined. In this experiment, all of the defective potatoes were detected by choosing a threshold level of 47 dB. It is also seen, however, that 4 normal potatoes are included in the defective region determined by the threshold level in Fig.

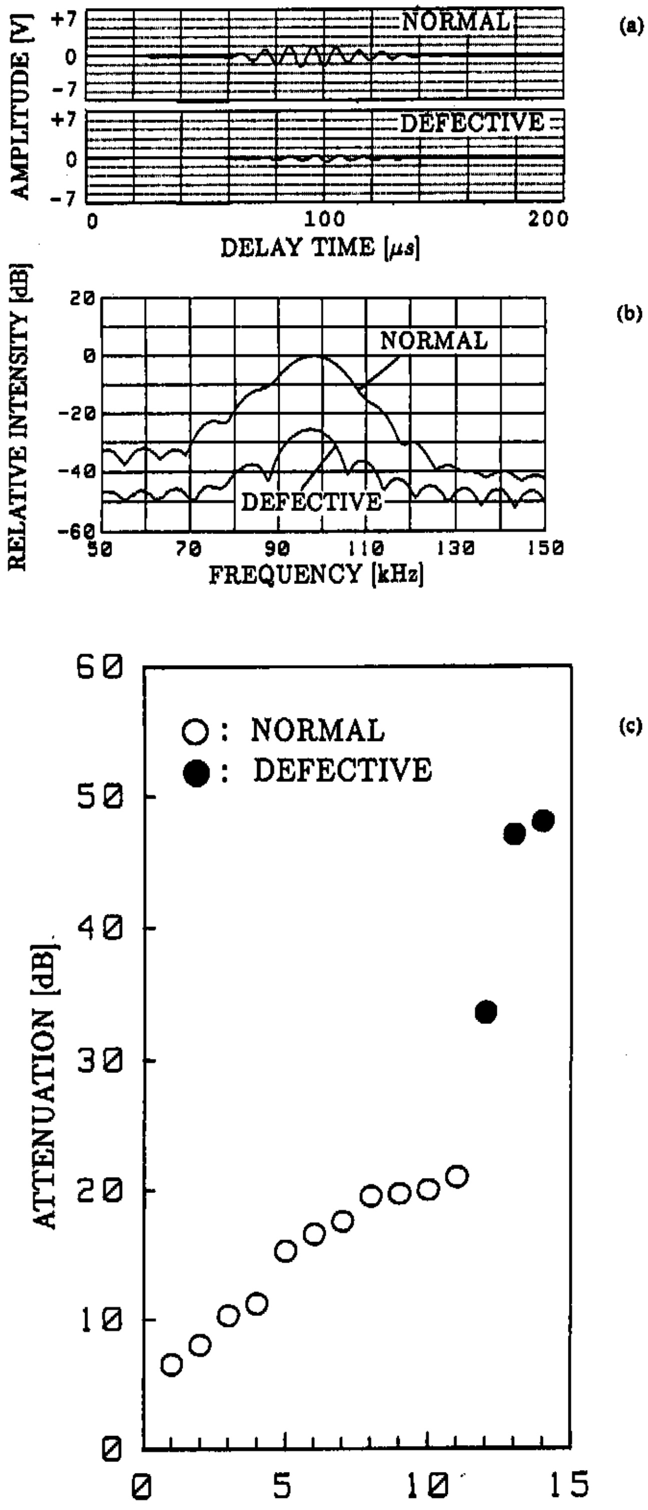

Fig. 5. Comparison of a defective potato with a normal one in waveform, (a), power spectra, (b), and the attenuation properties of 14 potatoes (100 kHz), (c). The normal potato is the same as that used in Fig. 3.

6. The attenuation for these normal potatoes was measured 3 weeks after they were harvested; thus freshness of the potato is assumed to affect the attenuation.

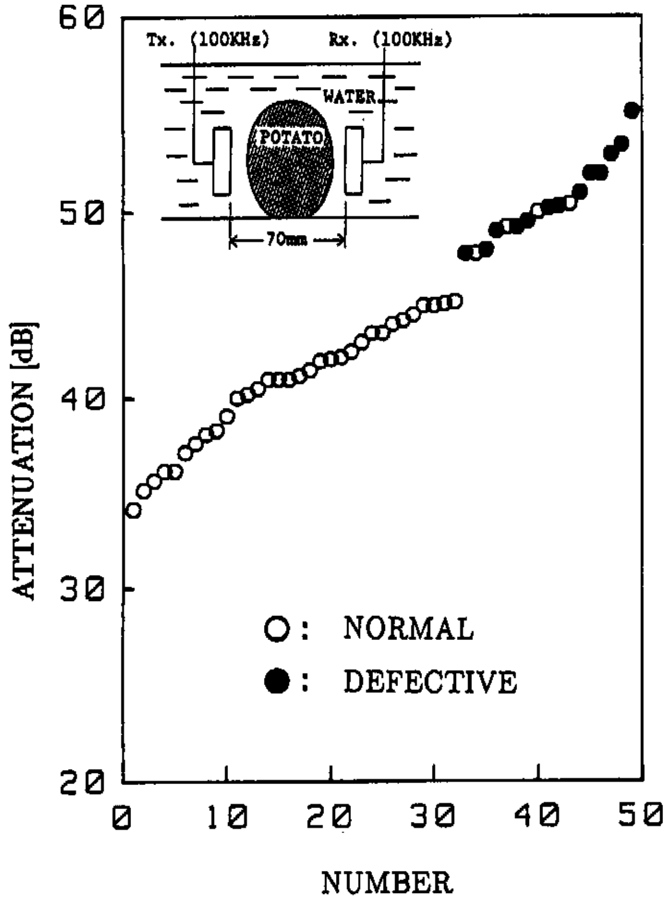

Fig. 6. Attenuation of normal and defective potatoes measured using a longitudinal ultrasonic wave of 100 kHz.

§4. Concluding Remarks

The acoustic properties of longitudinal ultrasonic wave in potatoes were measured to detect internal defects nondestructively. The average velocity in normal fresh potato was determined to be 824 m/s but had a large amount of scatter. On the other hand, there was a significant difference in attenuation between normal and defective potatoes.

It is necessary to further study the relation among attenuation, the size of the defect, and the freshness of the potato in order to develop an effective system. However, based on the results of this preliminary study, such a system does seem feasible.

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