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A Proposal to Measure a Thin Layer Thickness More Accurately

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1. Introduction

Due to the improved image resolution, attempts to measure a very small size of interior of biological tissue has been increased by using an ultasonic sonography. For example, an accurate thickness measurement of thin layer such as intima and media of cartoid blood vessel can help to diagnose hypertension or hyperlipidemia. [1]

In the present work, an envelope of linearly superposed echo signals from front and rear surfaces of a thin layer, which corresponds to the gray level of a scan line along the elevation direction of ultrasonic B-mode image, and the -20 dB width of the envelope were calculated numerically by using a computer program based on the fundamental reflection theory for thin layer boundary. The incident pulse was assumed to have gaussian shape. In many practical cases, the pulse widths of transmitting from different devices are not same. Therefore, the numerical calculation was made while varying the pulse width.

The results shows that the -20 dB widths of the envelope depend on the layer thicknesses. Hence, a thickness phantom and the method to measure a thickness of thin layer by using the phantom were proposed.

2. Materials and Methods

The reflection of acoustic pressure wave at the simple boundary of a thin layer between two different materials is given as follows: [2]

$$P_e = P_f + P_b \qquad (1)$$

where $P_f = RP_{g1}\, e^{iwt}$ and $P_b = R_{tl}P_{g2}\, e^{iwt}$ are reflected waves at the front and rear surfaces, respectively. $P_{g1} = \exp[-(t- t_1)^2/ \sigma^2]$ is the gaussian amplitude of the wave reflected to the front surface and $P_{g2} = \exp[-(t- t_1 - t_2)^2/ \sigma^2]$ is the gaussian amplitude of the wave reflected to the rear surface of the thin layer. w is the angular frequency, The time delay $t_1 = 2x/c_1$ is the flight time to return back from transducer to front surface (x) and $t_2 = 2L/c_2$ is that from front to rear surfaces of the thin layer (L). c_1 and c_2 are the sound speeds in the corresponding materials 1 and 2, respectivly.

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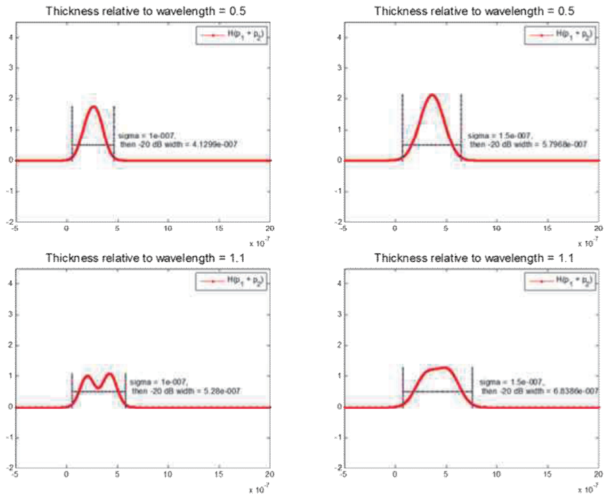

Fig. 1. -20 dB duration of echo pulse envelope for different layer thickness and Gaussian width of original incident pulse.

The reflection coefficient R in the above is for front boundary surface of the thin layer.

$$R = (z_2 - z_1)/(z_2 + z_1) \qquad (2)$$

where z is apecific acoustic impedance, subscripts 1 and 2 denote medium and thin layer, respectively. Another reflection coefficient R_{tl} is for rear boundary surface of the thin layer.

$$R_{tl} = \frac{[A\cos L_k + iB\sin L_k]}{[C\cos L_k + iD\sin L_k]} \qquad (3)$$

where $L_k = 2kL$, $A = 1 - z_1/z_3$, $B = z_2/z_3 - z_1/z_2$, $C = 1 + z_1/z_3$, and $D = z_2/z_3 + z_1/z_2$.

For this numerical calculation, the specific acoustic impedances of materials are assumed as $z_1 = 1.61$ MRayl, $z_2 = 1.63$ MRayl, $z_3 = 1.60$ MRayl, and the sound speeds are assumed as $c_1 = 1570$ m/s, $c_2 = 1540$ m/s, $c_3 = 1580$ m/s. As seen in Fig. 1, the Hilbert transform of reflected echo pulse P_e was performed to extract the envelope of the pulse, and its normalized -20 dB width L_{-20dB}/λ was also calculated with the variation of thin layer thickness relative to wavelength ($L_\lambda = L/\lambda$) for various gaussian width relative the period (σ/T) of the incident gaussain pulse. In here, $L_{-20dB}=c_2\delta t_{-20dB}$ (in time domain: δt_{-20dB}) is -20 dB pulse width as a

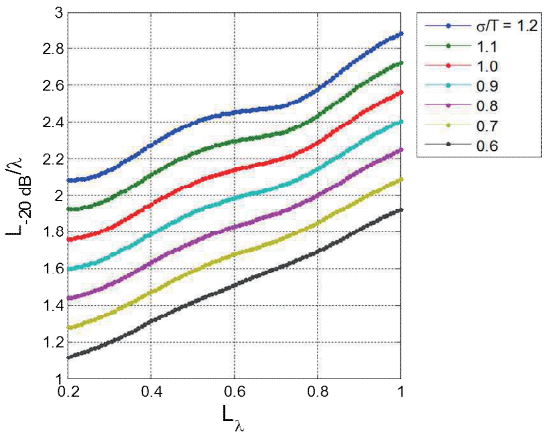

Fig. 2. -20 dB widths of the envelope vs thickness of thin layer for various pulse durations.

distance scale, $\lambda = c_2/f$ is the wavelength, and the frequency f is 10 MHz.

3. Results and Discussions

As seen in Fig. 1, L_{-20dB}/λ clearly depends on both L_λ and σ/T. But as seen in Fig. 2, the dependency is not linear. For short duration pulse, the dependency asymptotes approximately to linear, but for long duration, the deviation from linear line increases.

Practically, the pulse durations excited by a certain pulse/receiver equipment for different transducers of same nominal center frequency are not same due to the inconsistant manufacturing process and kinds of piezoelectric material, backing material, and matching material. Moreover, if we use the same transducer but different pulse/receiver equipments, the excited pulse durations might not be same because of frequency response, operating condition setup of the device, and so on.

In order to get the consistent and accurate measurement results of thin layer thickness by using ultrasonic sonography image regardless the kinds of devices, a new means is necessary.

4. A Proposal of a New Phantom

A proposed thickness phantom composed of three mimicking materials such as blood, soft tissue, and muscle is given in Fig. 2. In the engineering aspect, the specific acoustic impedances of the three materials should be importantly considered to choose proper materials. The specific acoustic impedance is a multiplication of density and sound speed which are important parameters of tissue mimicking quality to affect echogenic property. [3]

The soft tissue mimicking thin layer in Fig. 2 has four thicknesses, which are proposed to have λ, $3\lambda/4$, $\lambda/2$, and $\lambda/4$ to calibrate the L_{-20dB}/λ in Fig. 2 easily. The blood mimicking material is proposed as a liquid phase to accomplish the role of

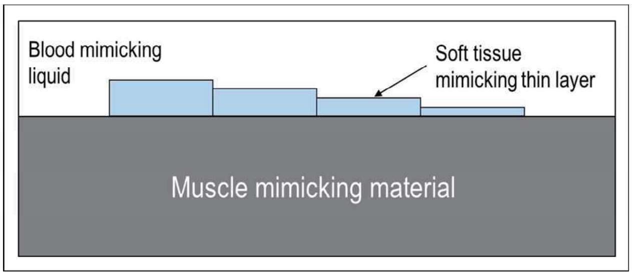

Fig. 3. Cross-sectional view of the proposed thickness phantom.

matching gel together. The muscle mimicking material is recommended to remove echogenic scatterer such as air bubble or other solid particles.

5. A Method to Use the Phantom

The procedure to measure a thin layer thickness by using the proposed phantom is also proposed in the this work. 1) Measure L_{-20dB}/λ values of four layers in the phantom by sonographic machine. 2) Find the σ/T of the device from the Fig. 1 by using the measured L_{-20dB}/λ and corresponding thickness. 3) Measure L_{-20dB}/λ values of the real membrane of interest by same sonographic machine. 4) Find L_λ from the curve corresponding to device σ/T in Fig. 2, and calculate the real thickness $L = L_\lambda \lambda$ of the membrane of interest.

The step 1) and 2) in the procedure described above correspond to device calibration. The step 3) and 4) correspond to the measurement by the calibrated device. After calibration of the machine using, the measurement can be repeated to thickness of other membrane of interest under the unchanged setup condition.

6. Concluding Remarks

In the present work, a phantom and the method to use with stepwise procedure by using sonographic machine. The proposal is based on the the numerical calculation results by computer program, The experimental work is remained in future work untill the fabrication of the proposed phantom with the help of acoustic impedance control method. [4]

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