ULTRASONIC MATERIAL CHARACTERIZATION SYSTEM EMPLOYING AN ARRAY OF RECEIVING TRANSDUCERS

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Abstract: In a typical ultrasonic material characterization system, the output voltage of the transducer is recorded as a function of the relative position of the transducer and the specimen. The velocity and attenuation of the leaky surface acoustic waves and the reflectance function for the immersion liquid–specimen interface can be obtained from the recorded data. The experimental arrangements with longitudinal movement of the transducer (the V(z) scheme) and lateral translation of the receiving transducer (the V(x) scheme) are well known systems. The disadvantages of these methods are obvious: the mechanical scanning of the transducer is associated with slow data acquisition, and precision mechanics is required.
In this work, we proposed a new measurement method based on recording the ultrasonic field distribution of the scattered wave with an array of the receiving transducers. The parameters of the leaky waves can be obtained by processing the set of the output waveforms. To experimentally confirm the proposed method, a new material characterization system has been developed. The relative position of the transmitting focused transducer and the receiving linear array of small transducers were constant in the experimental setup. The system was successfully tested on several materials with known acoustical properties.

Introduction: Measurements of phase velocity and propagation attenuation of Leaky Surface Acoustic Waves (LSAW) are widely used for material characterization. In most of these quantitative ultrasonic material characterization (UMC) systems, the output signal is recorded as a function of the relative position of the transducers and the specimen immersed in a liquid. In the V(z) technique, the point–focused or line–focused transducer is translated perpendicular to the surface of the specimen (Fig. 1). Many modifications of the V(z) technique employing various types of focused transducers, processing algorithms, and electronic equipment have been proposed. Typically, the phase velocity and propagation attenuation of the leaky guided waves, such as leaky Rayleigh, Lamb, skimming longitudinal waves, etc., as well as a reflectance function for the specimen–water interface can be obtained from the recorded V(z) data [1–5]. Recently, several ultrasonic material characterization systems based on lateral scanning of the receiving transducer along x axis have been developed [6-9]. In comparison with the V(z) system, the V(x) scheme potentially possesses better angular resolution and temperature stability. The disadvantages of these methods are obvious: the mechanical scanning of the transducer is associated with slowness of the data acquisition, and the accuracy of the measurements depends on the precision of the mechanical movement.

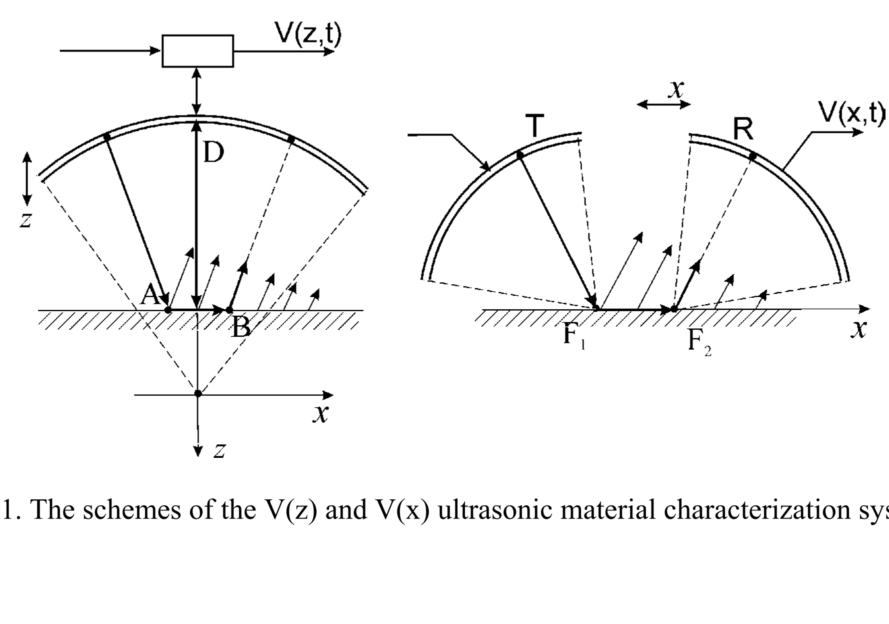

Fig. 1. The schemes of the V(z) and V(x) ultrasonic material characterization systems.

We propose a material characterization system based on the receiving of the reflected wave with an immovable ultrasonic array. The scheme of the proposed UMC system is shown in Fig. 2. The LSAW is generated in a local area of the immersed specimen by the single focused transducer T. The leaky wave propagates along the surface of the specimen reradiating back in the immersion liquid, and the reflected wave is received by the linear ultrasonic array tilted at the angle θ_0.

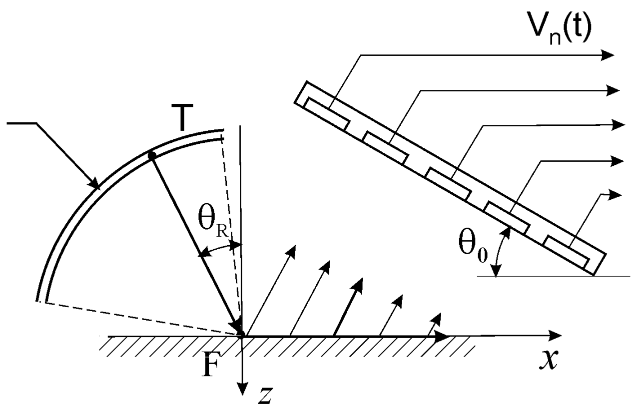

Fig. 2. The UMC system with the array of the receiving transducers.

The output waveforms of the elements of the array $V_n(t)$ represent the spatio–temporal distribution of the reflected waves in the plane of the array. The velocity and attenuation factor of the LSAW can be obtained by processing the $V_n(t)$ data.

Based on the geometry of the problem and ray model of the system, it can be shown that the relative time delay Δt between LSAW responses received by two neighbor elements of the array is related to the critical angle of the leaky wave θ_R by the following equation:

$$\Delta t = \frac{p}{C}\sin(\theta_R - \theta_0) \quad , \tag{1}$$

where C is the sound velocity in the liquid, and p is the pitch of the array. Using the measured value of Δt, the phase velocity of the non dispersive leaky wave C_R can be calculated according to Snell's law.

Let us consider now the amplitudes of the responses of the neighbor elements. For a particular frequency f_0, the ratio of these amplitudes η can be written as:

$$\eta = \exp\{(-\alpha \cdot \cos(\theta_0 - \theta_R) + \alpha_w \cdot \sin\theta_0) \cdot \frac{p}{\cos\theta_R}\} \quad , \tag{2}$$

where α_w, and α are the attenuation factors of the longitudinal wave in the immersion liquid and the leaky wave, respectively. Using the handbook value of α_w, the critical angle θ_R determined earlier, and the measured amplitude ratio η, the attenuation factor of the leaky wave α can be obtained by solving this equation.

Results: Fig. 3 shows a block diagram of the proposed UMC system employing an ultrasonic receiving array. A broad band lens–less line–focused transducer was used as a transmitter. The active element of the transducer was fabricated from metallized polyvinylidene fluoride film (PVDF; Measurement Specialties, Inc.) and was attached directly to the cylindrical surface of the transducer. The thickness of the piezo film was 52 µm, the thickness of the silver ink electrodes was 6 µm, and the backing material was an epoxy resin. The focal distance and the half–aperture angle of the transducer were 20 mm and 30º, respectively, and the length of the line focus was about 10 mm. In the experimental setup the transducer was mounted at an angle of 45º.

The 32 element receiving linear array had a central frequency and bandwidth of 17 MHz and 70 %, respectively. The pitch of the array was p=0.25 mm, and the length of the active area of the elements was 8 mm. In the setup the array was precisely mounted at the angle θ_0=22.9º. By using mechanical manual stages, the system was adjusted so that the line focus of the transmitting transducer was positioned on the water–specimen interface, the line focus and the long sides of the rectangular elements of the array were parallel to the surface of the specimen.

An analog multiplexer was used for sequential connecting of the elements of the array to the input of the Ultrasonic Pulser Receiver system (UT 340; Utex Scientific Instruments Inc.). The amplified and filtered waveforms $V_n(t)$, where n=1,…32 is a channel number, were digitized by an oscilloscope (TDS520C; Tektronix) and transmitted via GPIB interface to a computer. The acquisition time of the full $V_n(t)$ data set was less than 200 ms.

The incident probing wave generated by the transmitting transducer produces the directly reflected wave D and the leaky wave R. The wave D is a cylindrical wave which line source is located at the point F. The time delay of the response D received by the array t_D can be expressed as a function of the distance between F and the plane of the array h and the position of receiving element in the plane of the array d:

$$t_D = \sqrt{h^2 + d^2} / C \qquad . \tag{3}$$

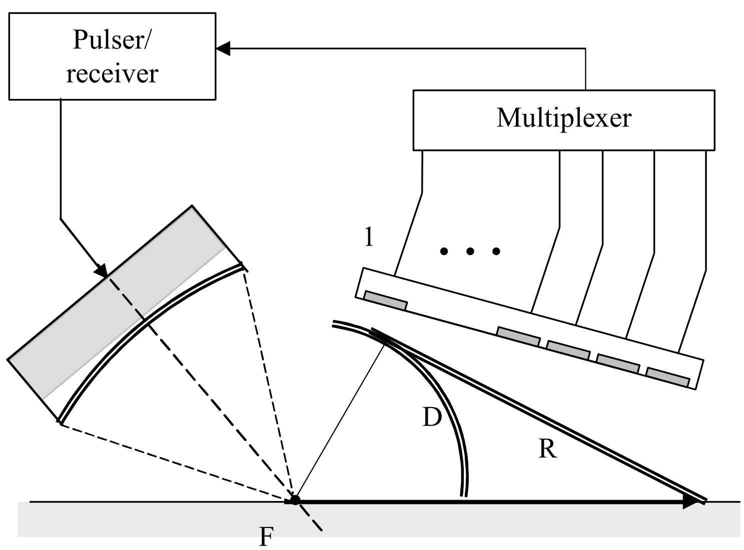

Fig. 3. The experimental setup.

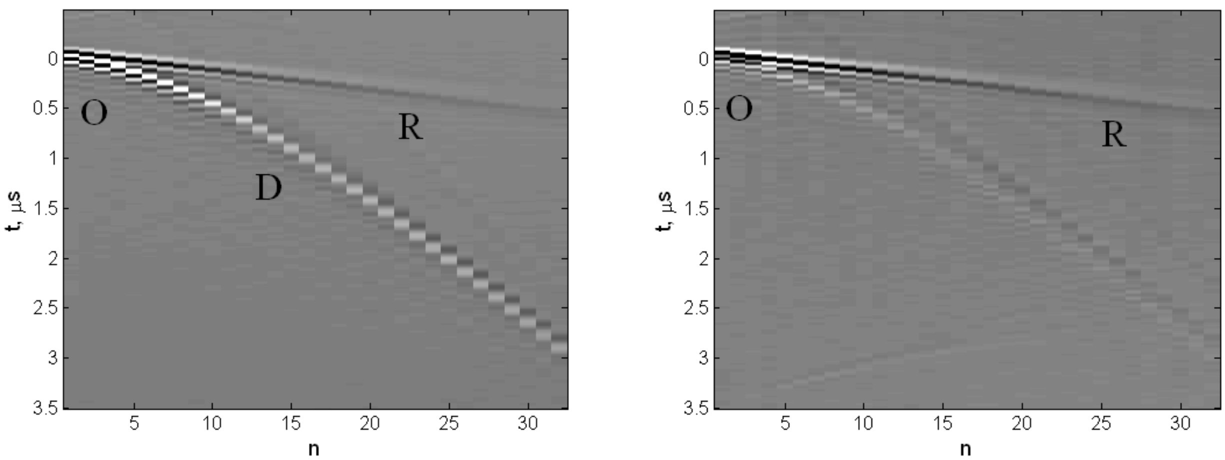

Fig. 4. The $V_n(t)$ data for aluminum alloy (left); the same data with the subtracted response D (right).
R and D indicate the leaky Rayleigh and directly reflected waves, respectively.

The $V_n(t)$ data recorded for aluminum alloy are shown in Fig. 4 as an example. The data are presented as grayscale images, and the vertical axes represent the time t, whereas the horizontal axes correspond to the channel number n. The responses R and D are clearly distinguishable in the $V_n(t)$ waveforms (left graph). The time of flight of the response R t_R depends practically linearly on the element number n, whereas for the wave D, the time of flight t_D is a non-linear function of n defined by the Eq. (3).

In the $V_n^{(D)}(t)$ data measured for lead (not shown), the response R is not observed. Due to the low values of the bulk wave velocities in lead, the leaky Rayleigh wave does not exist at the water–lead interface. Therefore, $V_n^{(D)}(t)$ is entirely determined by the wave D and can be considered as a characteristic response of the UMC system itself. Subtracting the system response $V_n^{(D)}(t)$ from the $V_n(t)$ data allows separate the response R as shown in Fig. 4 (right graph).

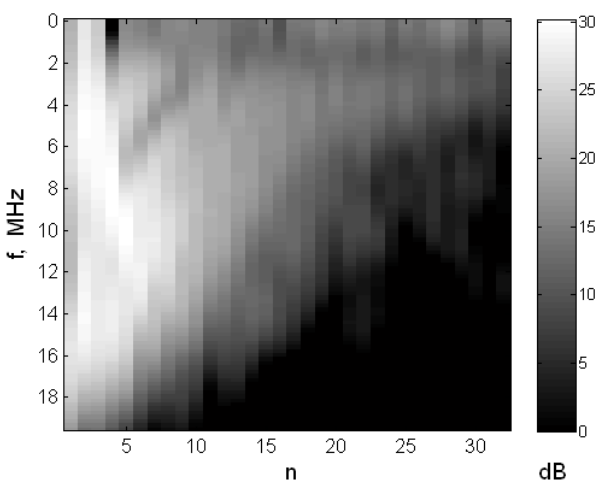

Fig. 5. The magnitudes of the spectra $S_n(f)$ calculated from the data presented in Fig. 4.

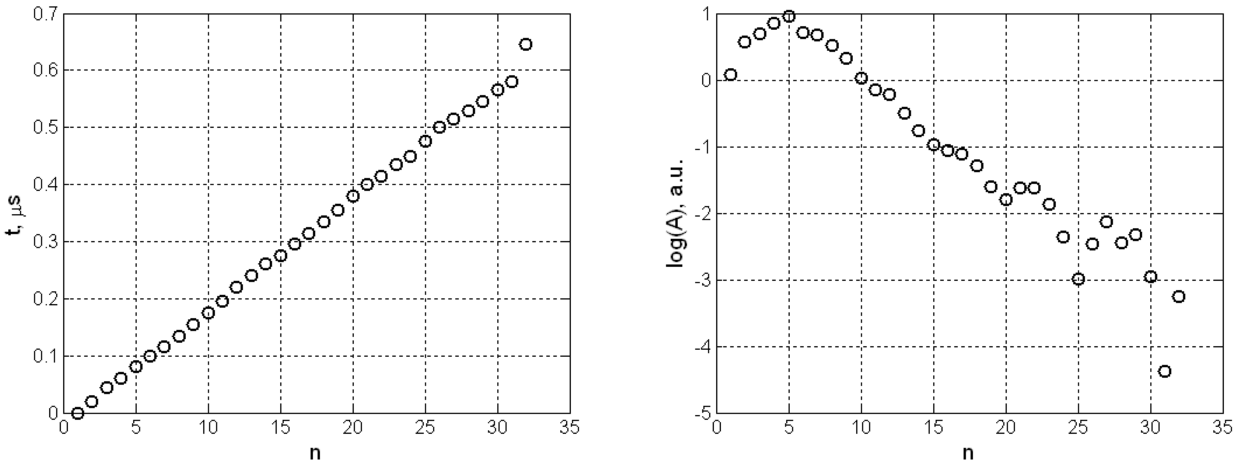

Fig. 6. The time of flight t_R and spectral magnitude (f_0=10 MHz) vs. the channel number n.

Discussion: To measure the velocity of the leaky wave C_R, the time delay of the negative peak of wave R was determined as a function of n (Fig. 6). Then, the average value of Δt was calculated and the velocity C_R was found according to Eq. (1). For the aluminum alloy specimen used in the experiment, the value of LSAW velocity was calculated to be C_R = 3008 m/s. To estimate the attenuation of the LSAW the spectra of the waveforms R was first calculated. The magnitudes of the spectra are presented for a full frequency range and for a particular frequency f_0=10 MHz in Figs. 5 and 6, respectively. Then, the average value of η was calculated based on decaying of the spectral magnitudes $A_n=|S_n(f_0)|$ with increasing of n, and the attenuation factor of the leaky wave was found by solving Eq. (2). The experimental value of the attenuation factor was estimated to be α=0.59 1/mm at a frequency of 10 MHz. For comparison, the LSAW velocity and attenuation were also calculated from the published values of the bulk wave velocities by searching the location of the pole of the reflectance function on the complex k_x plane, where k_x is the component of the wave vector. There is good agreement between the measured and calculated LSAW parameters.

Conclusions: A new ultrasonic material characterization system using an array of receiving transducers has been developed. In the proposed method, the acoustic field of the leaky guided wave propagating along the specimen – immersion liquid interface is recorded by the immovable linear array. The velocity and attenuation factor of the non dispersive leaky wave can be obtained by processing the output waveforms of the array $V_n(t)$.
The results of the theoretical consideration were confirmed by the test experiments carried out in the 20 MHz frequency range. No mechanical scanning of the transducers was used in the experiment. The time of measurement in a local area of a specimen was less than 0.2 s, and in the future design it may be remarkably reduced by employing a fast multiplexer and data acquisition electronics.

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