

AN AUTOMATED ALGORITHM FOR SIMULTANEOUSLY DETERMINING ULTRASONIC VELOCITY AND ATTENUATION*

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Ultrasonic investigation in materials relies mainly on the study of the behavior of propagation velocities and attenuation. The paper aims to cast a new light on the accuracy of ultrasound based measure of acoustic parameters of materials. Such a capability becomes a necessity in the ultrasonic evaluation of a component when service conditions have changed both its material properties and physical dimensions.

In this work we describe an automatic algorithm requiring one transducer (pulse-echo technique) that permits the simultaneous and automatic determination of the ultrasonic velocity (and elastic constants), peak attenuation, spectral analysis of the sample, reflection coefficient, and sample density.

The proposed algorithm must run automatically, must be stable in the presence of material and electronic noise and must be reasonably fast since it is required to analyse rather large data sets. The algorithm works in the time domain by determining velocity and in the frequency domain by determining attenuation versus frequency. For each measured point, the saved information consists of the amplitude and TOF determined from the reflected RF signal. The main parts of this system are the followings: a PC (233 MHz), a National Instruments A/D board, a SONIC-136 Ultra (Staveley Corporation) and a stepping motor controller.

As an option, the algorithm permits to compute grain size by Rayleigh scattering [1].

We also describe here validation data of this algorithm using a solid sample (Ni, Ge, Si, Al, Mo) welding joint and bone. In all cases, an accuracy of better than 2% is obtained when the system is compared with literature data.

1. INTRODUCTION

In the domain of ultrasonic material characterization, velocity and attenuation are among the most widely used quantities. In this case, the velocity is determined by insonifying the sample and recording the TOF of the respective front surface echoes if the thickness is known. In this paper we describe a technique requiring only one transducer E-R (pulse-echo technique) that permits

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the simultaneous and automatic determination of the ultrasonic velocity, peak attenuation and spectral analysis of the sample. Such an automatic technique serves first of all the increase in the speed of data interpretation. However, a very important goal is the increase of the reliability and reproducibility of the investigation. Ultrasonic spectral analysis is a method for testing materials with relatively low acoustic attenuation. By progressively sweeping the frequency of a driving transducer across a range and recording the amplitude and TOF (time of flight) of a receiving transducer one can build up a spectrum of the sample. There are some requirements regarding the algorithm for a successful automation of the analysis procedure as it follows:

- it must run automatically and does not require input from a human operator on a point-by-point basis,
- it must be stable in the presence of material and electronic noise,
- it must be robust i.e. it must be able to handle reasonable variations in material velocity and attenuation and must give correct results,
- it must be reasonably fast since it is required to analyse rather large data sets.

These requirements are not easily fulfilled because they present severe constraints on the development of a truly automated approach for simultaneous determination of velocity and attenuation using frequency domain analysis techniques. The data must be windowed before the FFT can be accurately computed. In order to implement successfully a frequency domain approach, a stable and robust technique must be developed which permits computerized identification of these windows. Considering the information mentioned above, we describe now the steps followed by the algorithm.

2. THE SYSTEM DESCRIPTION

The experimental system has two parts: an automatic mechanical system for immersion scanning and data analysis software an (algorithm) for the determination of the velocity and attenuation. The automatically mechanical system allows the displacement over three degrees of freedom with a maximum displacement of 100 mm in each direction according to the immersion technique. The transducer displacement is achieved using several step-by-step motors (1,8 deg/step) while the automated position control is accomplished through the acquisition software USCAN95 [2]. In each measurement point, the obtained data are conveyed through the serial interface RS-232 to the PC and then are saved under the form of data files. For each measurement points the following information are saved: radio frequency signal, amplitude and time of flight. The main parts of this system are: a PC (233 MHz), a National Instruments A/D board, a SONIC-136 Ultra Instrument, a stepper motor controller (Fig. 1).

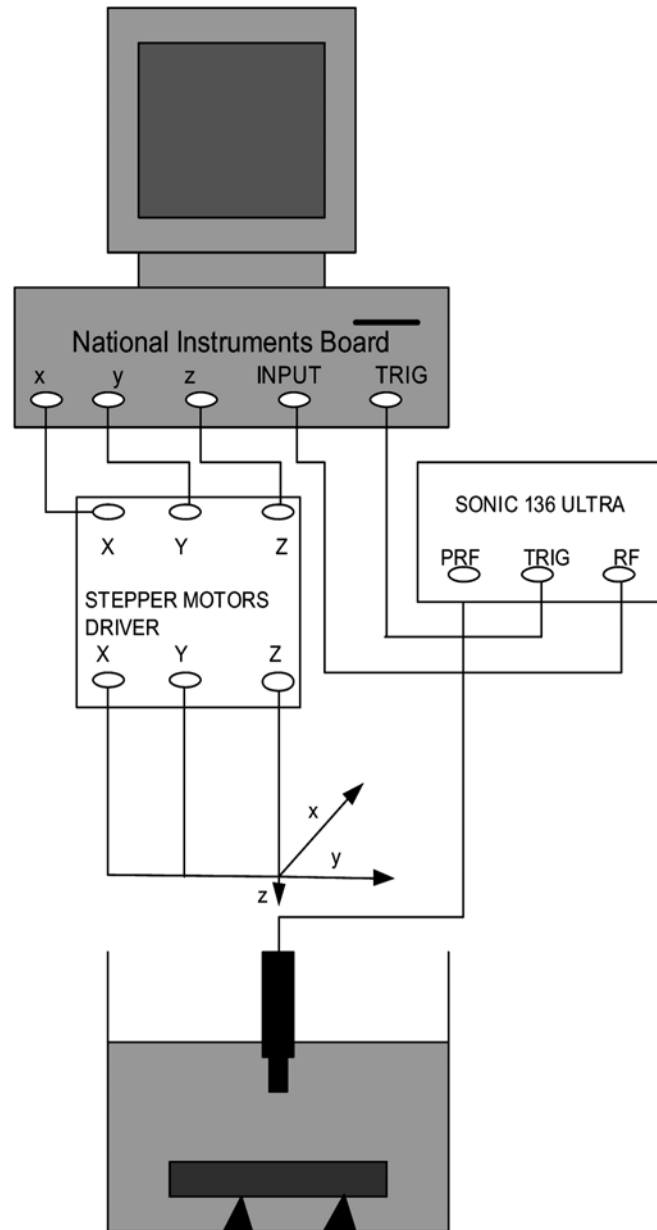


Fig. 1. – Experimental system.

When a material is traversed by an ultrasonic signal, the components of the initial signal are modified. This is more clearly set off in the frequency domain rather than in the time domain where it is also evident. FFT is used to obtain the information in the frequency domain. Analyzing in frequency the reflected

signals, it is possible to compare the effects on the material properties. Thus, an emission impulse will have a frequency spectrum, which varies after traverses different materials. A spectral analyse in frequency implies a differential analyse of the successive echoes from the time domain deriving from the same emission impulse. Each impulse from the time domain will be more attenuated than its predecessor. In the frequency domain, the amplitude ratio for some frequency components forms the basis for determining the functional relation between attenuation and frequency [3, 4].

The automated algorithm has been conceived and carried out for the ultrasonic investigation of material and structure characteristics. An analysis of the frequency spectrum involves differentiation of two successive echoes E_1 and E_2 obtained from the time domain, being generated from the same emission impulse. Then, based on FFT, the power spectra of the echoes S1 and S2 are determined. The ratio of the two power spectra in the region of the peak allows the computing of the ultrasonic attenuation. In the frequency domain, the amplitude ratio for a series of frequency components forms the basis for the deduction of the functional relation between the attenuation and the frequency. After obtaining ranges S1 and S2 corresponding to the selected echoes, the results are graphically displayed indicating the peak frequency and the amplitude corresponding to the peak frequency. The automated algorithm permits the selection of a frequency range in order to obtain the frequency dependence of the attenuation. Because the calculation includes the amplitude of two echoes, this method is susceptible to errors due to unusual echo shapes arising from sidewall reflections and nonparallelism.

The correction calculation concerning the attenuation depending on the chosen configuration is shown in [5]. The three windows which constitute the algorithm are shown in Fig. 2.

In the first window are visualized the echoes from the time domain and also the input data; in the second window is shown the superposition of the two echoes E_1 and E_2 and also the FFT and the velocity values (an Si sample it was used). The last window visualizes the attenuation dependence on frequency determined experimentally and theoretical from equations 1, 2, 3, 4. In this window one can compute the reflection coefficient R , the acoustic impedance Z_m and the sample density ρ . Visually, in a window of the algorithm appears the graphic of the experimental results and the theoretical curves fitting in the frequency domain as:

$$\alpha(f) = af + bf^4 \quad (1)$$

$$\alpha(f) = af + bf + cf^4 \quad (2)$$

$$\alpha(f) = a + bf + cf^2 + df^3 + ef^4 \quad (3)$$

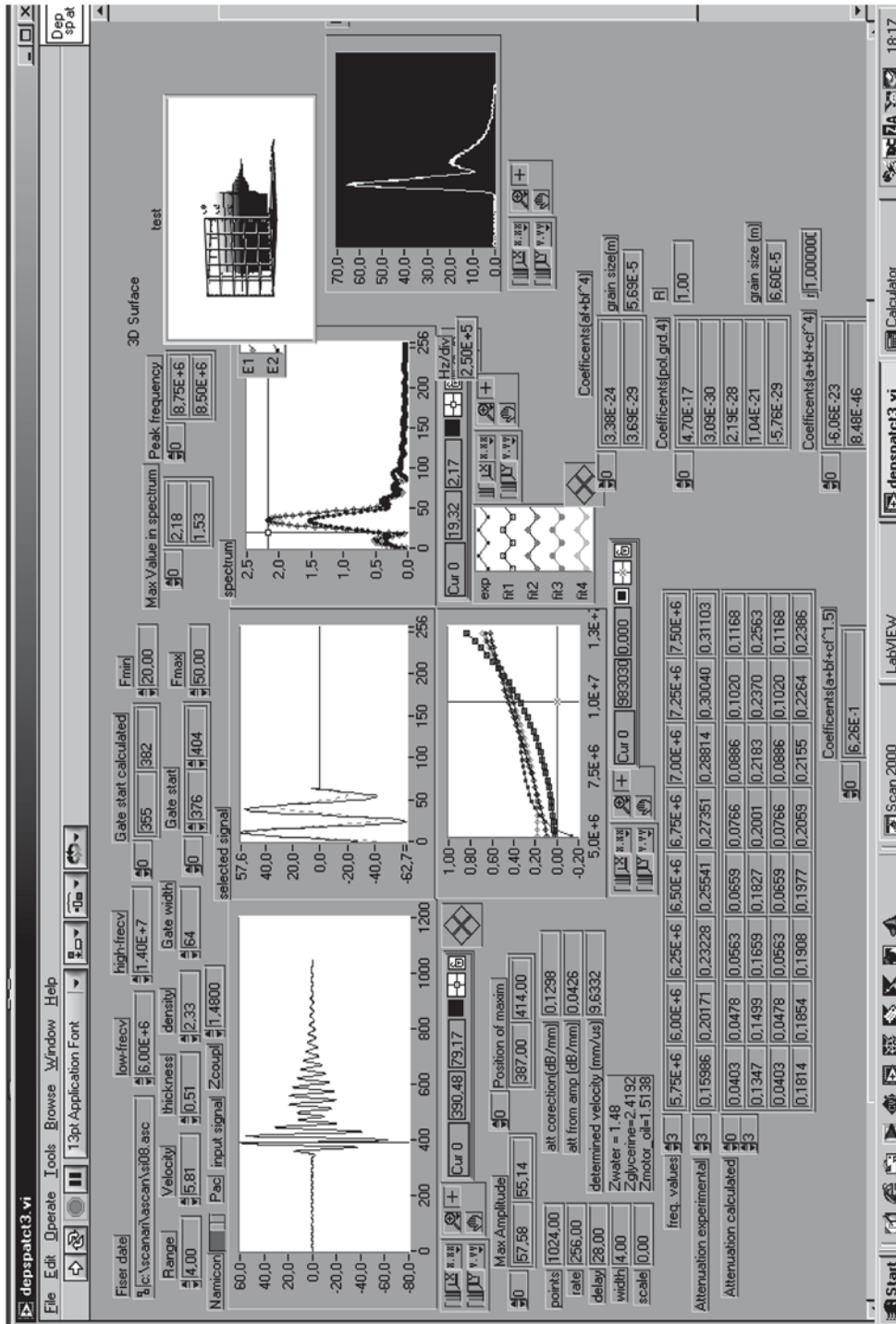


Fig. 2

$$\alpha(f) = a + bf \quad (4)$$

where equation (1) represents the expression of the attenuation $\alpha(f)$ in Rayleigh scattering.

By directly utilizing the time domain data for analysis, the algorithm runs automatically once the initializing parameters are given.

3. THE ALGORITHM

The input data of the algorithm consists of: sample thickness, sample density, preliminary propagation velocity (obtained independently by the conventional A-scan method and used only for the determination of the real time), gate width and range.

The algorithm performs the following tasks: determines the attenuation at peak frequency, computes the propagation velocity, selects the first two echoes E1 and E2, translates E2 for an overlap with E1 by applying a criterion for maximum coincidence, performs the FFT of the E1 and E2 echoes, obtains S1 and S2, computes the spectrum amplitude ratios: $B(f) = \frac{S_1}{S_2}$ over a specified frequency range, computes the diffraction correction required by the chosen configuration, performs the curves-fitting of the frequency dependence of the ultrasonic attenuation and computes the fitting coefficients (equations 1, 2, 3). The output file of the algorithm provides the calculated propagation velocity, determines the attenuation at peak frequency, the attenuation in the given frequency range and the calculated polynomial coefficients of the proposed theoretical dependence $\alpha(f)$.

For the purpose of automating the technique, the main task is to develop a suitable program for the determination of the TOF giving the RF time domain traces in a digital format, along with other information. The first step in this procedure is to obtain a row data set comprising a RF signal containing the echoes needed to determine TOF. A RF signal from the SONIC-136 Ultra excites the transducer to launch an ultrasonic impulse into the sample. Measurements are made with only two successive echoes displayed in the time window. Each window is digitized into 388–2560 points. An arbitrary number of high frequency cycles are selected from each echo; the choice of the number of cycles to be used is determined by the shape of the echoes and the fact that the shape of the echoes may alter as a function of attenuation due to sidewall reflections and the effects of non-parallelism in the sample. The data obtained at each measurement point with the ultrasonic instrument SONIC-136 Ultra are delivered through the serial interface RS-232 to the PC and then saved as data files.

For each measurement point the saved information consists of the amplitude and TOF determined from the reflected RF signal. The main parts of

this system are a PC (233 MHz), a National Instruments A/D board, a SONIC136 Ultra instrument and a stepping motor controller. Only one transducer and its associated electronics are required to acquire the raw data. Once the traces are acquired, they are analysed according to the flow chart of the software algorithm given in Fig. 3. We shall explain the running of the system for the case of measuring ultrasound velocity, peak attenuation and attenuation as a function

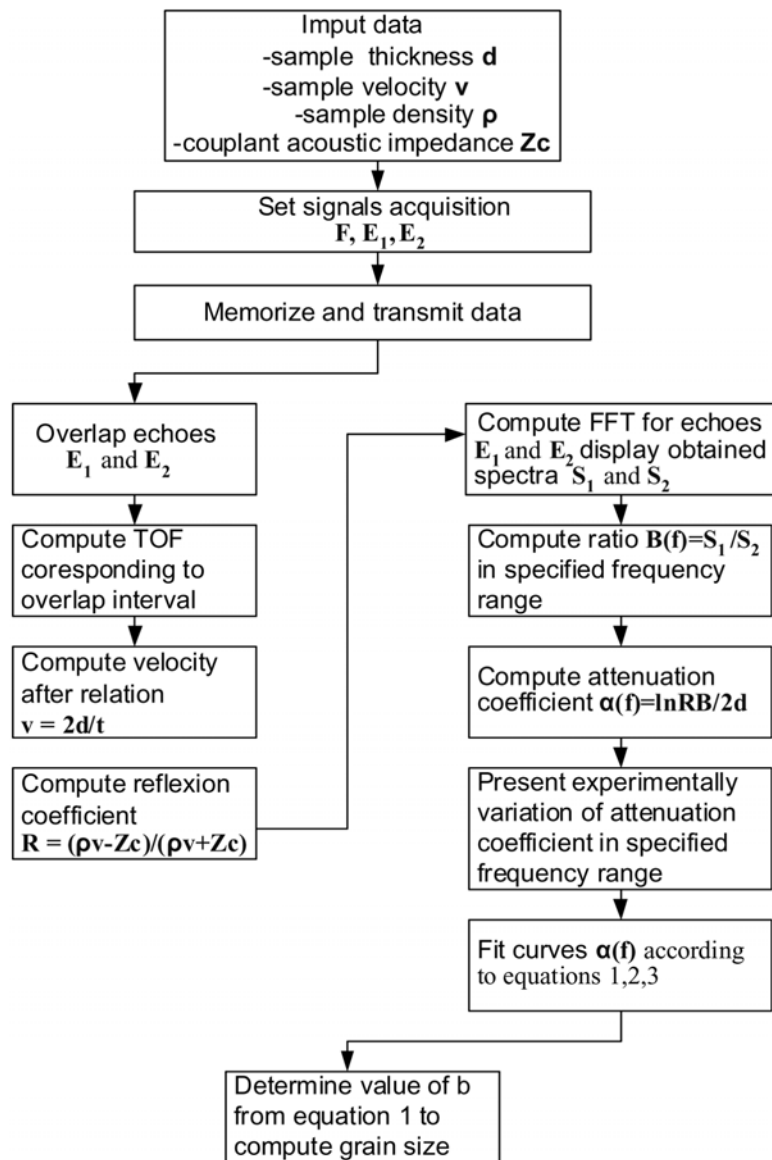


Fig. 3. – Flow chart of the algorithm.

of frequency. In the first window are recorded and memorized the two successive RF echoes E1 and E2 in the time domain. After repeated attempts, the optimum interval for the two echoes overlap is found. Frequency peaks appear automatically in a new window (the real transducer frequency it is found which can be different from the one written down on the transducer). Then, a new windows it is obtained by FFT, in the frequency domain when the attenuation dependence on frequency it is shown experimentally and for all mathematics models expressed by equations 1, 2, 3, 4.

Analyzing the curves obtained experimentally by equations 1, 2, 3, 4 one can determine the proper coefficients. The algorithm presents an option of the equation (1), in the case of Rayleigh scattering, where coefficient “b” is computed and the grain size is determined.

The value of the propagation velocity in the tested sample appears in a different window with a precision of 4 decimals.

The same way, the attenuation values at peak frequency and the attenuation correction appear.

4. EXPERIMENTAL RESULTS

The experimental results regarding the values of longitudinal ultrasonic velocities for different studied materials are shown in Table 1.

A careful analysis of the table shows that the velocity values obtained by the algorithm have four decimals, namely they are more precise and more sensitive to small variations of temperature and pressure.

The differences which appears comparative to literature depend on the composition of the studied material, on the transducer-sample orientation, on the non-parallelism of the lateral surfaces or on the used method: direct contact or in immersion.

REFERENCES	Si	Ge	Al	OL	Cu	Ni	KCl	bone
WE	9.2579	5.5444	6.2538	5.9276	4.6335	5.5385	4.5585	3.2665
1	9.13	5.56	6.32	5.90	4.34	5.63	4.48	–
6	–	5.41	6.32	5.90	4.66	–	–	2.70 4.14
5	–	–	6.32	5.90	4.70	5.63	–	–
7			6.22	5.85	4.60	5.63		
8			6.35		4.70	5.63		

5. CONCLUSIONS

We have described and developed an automated algorithm for the simultaneous determination of sample velocity, attenuation of peak frequency

and attenuation vs frequency. The algorithm works in the time domain by determining the velocity and in the frequency domain by determining the attenuation vs frequency, both based on the same data set.

It is fully automated, stable in the presence of noise, robust and fast in real time. Moreover, we considered that the algorithm can represent a new and fast method for determining the grain size, the reflection coefficient and the sample density.

The experimental system has two parts: an automatic mechanical system for immersion scanning and data analysis software for the determination of the velocity and attenuation. The automatically mechanical system allows the displacement over three degrees of freedom with a maximum displacement of 100 mm in each direction according to the immersion technique. In each measurement point, the data obtained by the ultrasonic instrument SONIC-130 Ultra are conveyed through the serial interface RS-232 to the PC and then are saved under the form of data files.

The experimental results obtained for the propagation velocity for different materials are in concordance with literature; the obtained values have four decimals. When it comes to attenuation, both experimental and theoretical results expose the same curve shape in the chosen frequency range. The algorithm has the advantage of being able to work in direct contact and in immersion. It utilizes a specially designed software package together with commercially available instrumentation.

The algorithm presents the advantage of a limitation of the researcher intervention and interpretation and of a bigger amount of information display by comparison with the A-scan method. Due to the complete and immediate visualization of the successive echoes in the time and frequency domains we came to the conclusion that the algorithm facilitates the display and the determination on of the acoustic parameters in real time. The use of automatic interpretation techniques increases the velocity of the data interpretation, the reability and reproductibility of the measurements. Also, the computer system can help to interpret complex data because they are capable of analyzing more data simultaneously.

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