COMPUTED AIDED SEMIAUTOMATIC DETERMINATION, AT LABORATORY LEVEL, OF THE SOUND SPEED IN SOLIDS, LIQUIDS AND GASES

PACS: 43.58 Dj

RANZ GUERRA, CARLOS ; FERNÁNDEZ FERNÁNDEZ, ALEJANDRO

Instituto de Acústica. CSIC.

C/ Serrano 144, 28006. MADRID. SPAIN

Tfn: 34-91-561 88 06. Fax: 34-91-411 76 51. E-Mail: iacrg32@ia.cetef.csic.es

ABSTRACT

This paper reports how can the sound speed, into any solid, liquid or gas media, be evaluated. The determination of the sound speed is done at laboratory level in a quick and simple way. The sole condition for the solid samples is to be limited in dimensions to fit into the sample holder of the measurement system; the fluids have to be put into some given receptacles. The system makes use of a generation and acquisition board controlled by a PC, that is not especially dedicated for this purpose. Some results are presented from which the accuracy of the evaluation can be shown.

INTRODUCTION

The Instituto de Acústica, CSIC, in Madrid, has been designing hydroacoustic transducers for thirty years. When designing such structures one of the fundamental parameters is the velocity of propagation of the sound in the materials of which the transducers are constructed for, (Cobo, 2002). If the experimental data are not existent the value of the velocities that are used in the design, comes from the specialized literature; i.e., despite de great variety of steel or aluminium alloys, materials very often used in the transducer design, the sound speed value used is the one associated to steel and, or, aluminium, without too much specification. These values are approximated values and the level of accuracy is, very often, unknown. Other times the sound velocity is evaluated through theoretical formulae that are a function of the Young's modulus, Poisson's coefficient and density. Unfortunately the manufactures very seldom give the three parameters at the same time, (Pierce, 1989). It is also a known fact that the plastic or synthetic materials are used in this work either for covering and isolating the transducers from water or making themselves part of the transducers. Once again is necessary to know the sound velocity in those materials, but not always the manufacturers include such a parameter or the data from where to derive the sound speed. It seems obvious that the need of having a system, or experimental device, that could help in measuring the sound velocity in a given material in a quick and easy way, would help and facilitate the transducer design procedure

The system to be described in this paper makes use of a data acquisition card connected to a computer (not necessarily dedicated to). The card generates a signal, that once is amplified, feeds a sound emitter that radiates the signal into the sample. At the other side of the sample another transducer picks up the signal. Specific software computes the sound speed, in the sample, by reading the time difference between the emitted and received signal. The system has been complemented by a support able to accommodate cylindrical samples of length between 170 and 570 mm, and 10 mm of radius. The support allows locating the signal transducers at the most adequate position in a quick, accurate and easy way. The use of the method to compute the sound velocity in fluids and gases implies to consider specific containers where to put the samples; the maximum dimensions of the containers coincide with those given above.The Sound Velocity Measurement System, works making evaluations of the sound velocity of propagation in samples with an accuracy limited by the card sampling time in terms of distance (500 kHz in the system described). The simplicity has always been a mark to look for in the whole design of the system, not only about how the samples could be manage but also with respect to the software that controls the data generation/acquisition and the sound velocity as well.

ADOPTED SOLUTION

The adopted solution was made from the following parts: A base to hold the cylindrical samples and the transducers; the piezoelectric transducers; the signal acquisition and generation card, DAQ, PCI-MIO 16E4 from National Instruments; standard PC where to insert the DAQ card; signal generation and acquisition software, velocity evaluation software, cylindrical solid samples and containers for fluids and gases under study

		Backing materials			Piezoelectric ceramics			Radiating head materials		
Para meter	Unit	steel	Al/bro nze	Navy Brass	PXE4	PXE41	PXE42	Titanium alloy	Dural	Magnesiu m alloy
ñ	$10^3 Kg/m^3$	7,85	8,50	8,37	7,50	7,90	7,80	4,42	2,79	1,74
c_l	m/s	5250	4070	3320	3220	2915	2850	4900	5130	4800

Table 1 *Some physical properties of materials used in high intensity transduction*

Basic Holder.

The simple and quick use of the measuring system is the main function of the base holder. This holder needs to allow samples of different dimensions (length and diameters) to be measured. The experimental process can be carried out at different frequency bands so the base also allows changing transducers, and then frequencies, in few seconds. The final dimensions of the base came out as a compromise between the largest expected speed to be measured, the sampling frequency of the card and the maximum dimensions of the samples (length between 170 mm and 570 mm, and 10 mm of radius. The samples support must also allow accommodating transducers of different sizes. In our system the transducers are inserted into specific supports that are whole interchangeable if any other frequency band is to be used, figure 2.

Transducers.

The transducer's selection comes out as the consequence of a series of factors like accuracy and capability of the measurement system. The accuracy is a function of the working frequency because the lowest error to be obtained will always be one ë. The DAQ board also limits this frequency. The type of narrow band transducers selected (37 and 48 kHz), figure 2, imply some limitations in the length of the pulse to be radiated into the sample; pulse shape techniques and correlation techniques are not very well suited due to amplitude and phase distortions into the "channel" because of the very narrow transducer's band; the measurement technique has to count on this disadvantage and unless a wider band transducer could be use the measurement technique has to lie upon the measurement of the time arrival of a given (as short as possible) pulse.

***Figure 1**. Support base holding an aluminium sample. One of the two transducers can be viewed on the left part of the figure.*

Measurement Method.

Because is not possible to use single picked signals to make time difference measurements the interest was focused on the detection, at the receiver, of the time where the signal is considered to start. This time would be the reference time. One of the difficulties then was to perfectly synchronize the emitted and captured signals. Moreover, is necessary to include a correction factor that takes into account the delays due to the transducers radiating heads, figure 3.

***Figure 2**. Two types of 36 kHz (left), and 48 kHz (right) resonant transducers inserted in the special holder*

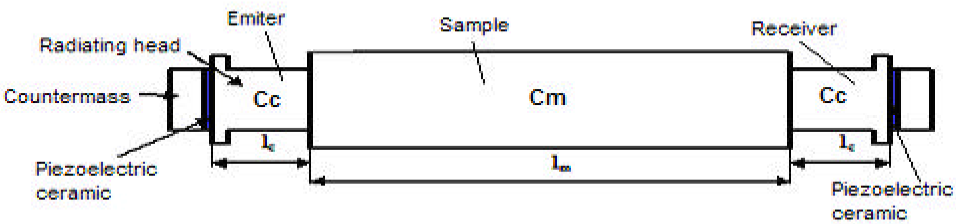

***Figure. 3**. Basic representation of the whole set: emitter, sample and receiver*

The source of the acoustic signal is the piezoactive layer, which in this case is located at the interface of the ceramic and the radiating layer. So the signal must travel through the radiating layer, the sample and again the radiating layer of the reception transducer before it is detected by the piezoactive layer. The time elapsed by going into the sample must be increased by twice the time spent by going into a radiating layer. Also the material that makes the transducers heads will, in general, be different from the one the sample is made, so the corresponding sound speed. In order to know and measure the delay generated by the radiating heads two samples of different length but of the same material were measured; in both cases the transducers remained unchanged. By substracting the two time measured values (each one has equal time delay introduced by the radiating heads), the result is a time value in which the delay of the transducers has been removed,

$$\Delta t = t_{m1} - t_{m2} = (t'_{m1} + t_c) - (t'_{m2} + t_c) = t'_{m1} - t'_{m2}$$

and the sound speed in the sample will be,

$$c_m = \frac{l_{m1} - l_{m2}}{t_{m1} - t_{m2}}$$

where, c_m: sound velocity in the sample, l_{m1}, l_{m2}: length of both samples, t_c: time delay introduced by the radiating layers, t_{m1}, t_{m2}: time interval measured in both experiences, (included the heads time delay), and t'_{m1}, t'_{m2}: time interval measured in both experiences, (excluded the heads time delay). Once the sound velocity in the sample is known it can be use to compute the time spent by the sound to go through both samples and by simply substracting these time values from those measured with the transducers included, the time delay generated by the presence of the transducers is finally evaluated. This value only depends on the transducers and is independent of the samples measured. This time has to be substracted from the time measured between emission and reception and will not change unless the transducer is varied. Table 2, gives the results of two samples of PVC for these particulars. Because the sound speed is not dependent on the frequency, once it was evaluated with the 37 kHz transducer only one measurement is required to make with the 48 kHz transducer.

	Measurement		Calculus	
Samples	**Length**	**Time**	**Velocity**	**Delay**
Sample 1	190 mm	94,09 ì s	2.271 m/s	10,4 ì s
Sample 2	577 mm	264,48 ì s	2.271 m/s	10,4 ì s
Sample 1 (*)	190 mm	94 ì s	2.271 m/s	10.34 ì s

Table 2. *Measured and calculated values for 37 kHz transducers. Samples of PVC. (*) refers to measurements done with a 48 kHz transducer.*

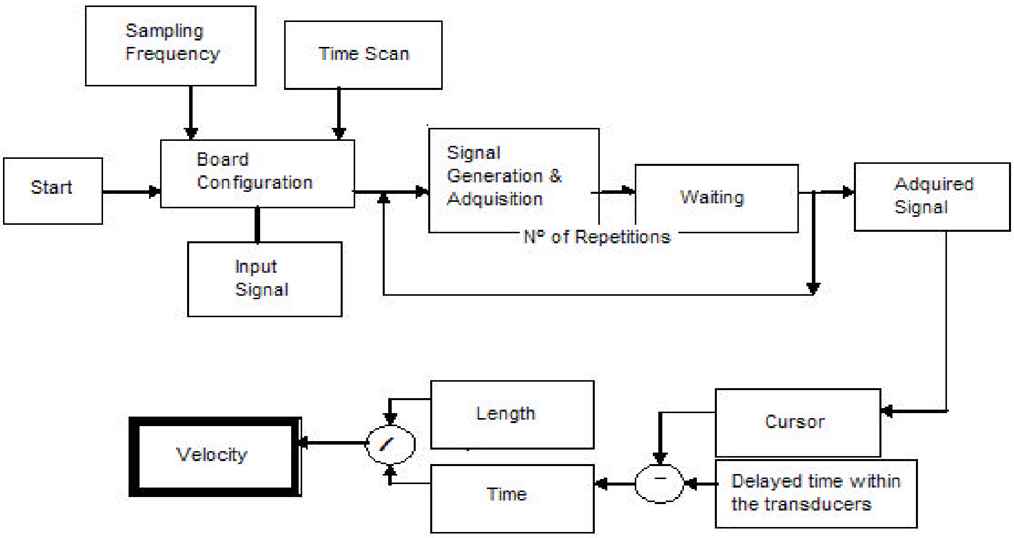

Figure 4. *Block diagram of the DAQ board program control and velocity estimator*

DAQ board control software and velocity estimator

All the actions related with the DAQ board control as well as those related with the estimation of the sound speed within the sample, were done in LabWIEW 5.0 environment to easy the communication to and from the PCI-MIO 16E4 board; the LabVIEW (graphic) language is, on the other hand, very intuitive and easy to use. The block diagram of the process is as follows, figure 4. During the acquisition the process selects, by "Time Scan", the length of the acquired signal, the waiting time (or number of repetitions) and also the file where the input signal is kept if it differs from the one selected by defect.Once the system starts, the program configures the input and output channels and the process go into a loop; in each step of the loop, the system performs one emission and one reception. The captured signal is stored in a buffer, which size depends on the sampling frequency and the "Time Scan", and is added to the previous results in such a way that performs an averaging process taking away all the random signal contributions due to noise. The sum is finally divided by the number of repetitions. The system gives then a graphical presentation of the result allowing the operator, by means of a cursor, to point at the start of the signal. The length of the sample is introduced into the corresponding window, and the sample travelling time, corrected by the time length due to the transducers, is calculated by the system, giving the final value of the estimated sound speed with the corresponding accuracy measured either in time or in length.

RESULTS

Table 3 present some results referring to some solids samples. The results dealing with steel, dural and PVC could be checked not only by two different frequency bands but also by two different sample length; the sound speed in those materials are very close to each other lying within the range error. In all the experiments the sampling frequency was 500 kHz. When working with fluids and gases the use of the system is very similar. The fluids fill specific receptacles, of different length, if necessary, figure 5. The enclosures were ended by two rubber like walls of 2.0 mm thick that will not introduce any significant error in the time measurement (the sound speed in the rubber like material is very close to that in water).

Material	Length	37 kHz Transducer		48 kHz Transducer	
		Velocity	Error	Velocity	Error
Steel	270 mm	5.671 m/s	± 4,39 %	5.771 m/s	± 4,47 %
	396 mm	5.606 m/s	± 2,91 %	5.600 m/s	± 2,91 %
Dural	395 mm	6.114 m/s	± 3,19 %	5.924 m/s	± 3,09 %
	417 mm	6.191 m/s	± 3,06 %	6.108 m/s	± 3,02 %
PVC	190 mm	2.356 m/s	± 2,54 %	2.271 m/s	± 2,45 %
	575 mm	2.270 m/s	± 0,8 %	- - -	- - -
Megalene	216 mm	2.236 m/s	± 2,11 %	2.264 m/s	± 2,14 %
Durester	400 mm	2.386 m/s	± 1,21 %	2.474 m/s	1,25 %
Graphite	367 mm	2.452 m/s	± 1,35 %	2.437 m/s	± 1,35 %

Table 3. *Results referring to solid samples of the most used materials*

Table 4 presents the values obtained for the sound velocity in certain fluids and in air at atmospheric pressure.

	Water (short)	Water (long)	Olive Oil (standard)	Olive Oil (Virgin)	Alcohol	Milk	Air
Velocity	**1.433,8**	**1.464,4**	**1.572,6**	**1.572,6**	**1.174,7**	**1.477,3**	**339,5**
Error	**1,49 %**	**0,6 %**	**1,64 %**	**1,64 %**	**1,22 %**	**1,54 %**	**0,29 %**

Table 4. *Sound velocity results in some fluids and gases. The velocity is given in m/s*

CONCLUSIONS

The measurement system described so far, allows getting values of the sound velocity in the materials of use in the transducers design. The accuracy of the measurement comes limited by the sampling time (or frequency) of the generation and acquisition board; in this instance is 500 kHz. Other factor that can affect to the accuracy also is the length of the cylindrical sample and the intrinsic sound speed in the sample: longer samples and lower sound speeds give higher accuracy. In the system the length of the samples is limited by the length of the sample holder (up to 580 mm sample length can be measured).

The measurement also is a function of the transducers used to act as emitter and receiver. It is important to have characterized these transducers in order to introduce the correction factor needed to make the exact evaluation of the sound velocity.

The method used in the measurement is very easy and quick. The operator only has to adjust the right position of the emitter and receiver in contact with the sample, operation that is rapidly done. Once this operation is finished the operator only needs to start the software up, to introduce the appropiated parameters and click the init button. The post study can be done going to the generated and acquired signals together with the sample dimensions stored in the corresponding file generated during the process.

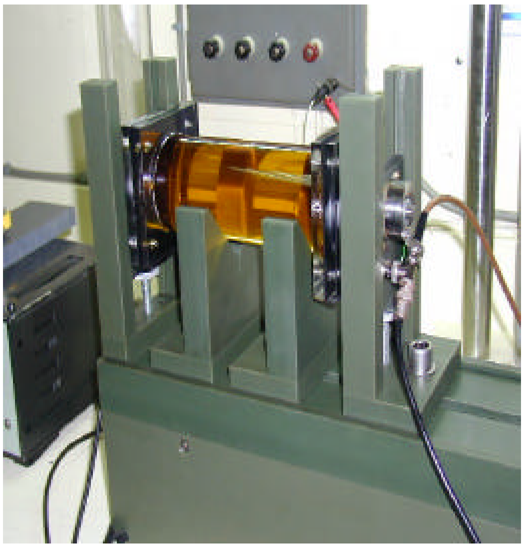

Figure 5. *Sound velocity measurement in a sample of olive oil*

All the reported measurements were checked against the sound velocities that are tabulated or can be computed from the mechanical parameters that intervene in the theoretical formulae. It is possible to assert that this comparison is very positive if the differences in sound speed caused by the differences in the composition in the alloy are not noticeable, (Fernández, 2001).

This system allows evaluating the sound speed in materials (i.e. very specific plastic like) that is not well known despite the interest of its use in the hydroacoustic transducers design**.**

ACKNOWLEDGMENT

The authors wish to express their acknowledgment to the colleagues of the Active Noise, Hydroacoustic Laboratory and workshop of CETEF, to A. Cabello for his invaluable help in the system design and to P. Cobo for his comments and suggestions

REFERENCES

Cobo, P., Ranz, C., y Cervera, M., *"Increasing the vertical resolution of conventional subbottom profilers by parametric equalization"*. **Geophysical Prospecting,** 2002, **50**, pp. 139-149.

Fernández, A. . *"Valoración de la velocidad de propagación sonora en muestras cilíndricas".* Proyecto Fin de Carrera. ICAI. Madrid. 2001.

Pierce, A, D. *"Acoustics",* A.S.A. 1989. New York. Chp. 3.