A Pulsed Technique for the Measurement of the Ultrasonic Attenuation

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Introduction

Viscosity is among the parameters which can be measured by using ultrasonic techniques. Viscosity can be determined by conventional viscometers or by ultrasonic methods. The ultrasonic methods can be divided into two groups. On group of these methods is based on the measurement of shear wave reflection. In the other group the viscosity is deduced from a measurement of the velocity and the attenuation of the ultrasonic waves. In this last group, correcting factors are often used in order to take into account the diffraction phenomenon resulting from the finite size of the ultrasonic transducers (transmitter and/or receiver).

If a rigid target of small surface is placed in the near field of a circular transducer, the emitted wave is completely reflected and, in transient mode, the detected pressure consists of three impulses arriving at different instants. Only the first corresponds to the plane wave. Here, we take the advantageous of the transient mode to select this impulse which is time resolved from the two others in order to deduce the attenuation coefficient without using any diffraction correcting term.

Theory

In viscous fluid media the attenuation of the acoustic waves is proportional to the square of the frequency f: $\alpha=\beta f^2$ and the propagation equation for the acoustic potential is [1]:

$$\nabla^2\phi-\frac{1}{C^2}\frac{\partial^2\phi}{\partial t^2}+\beta\frac{\partial}{\partial t}\nabla^2\phi=0 \qquad (1)$$

When the acoustic wave is radiated by a plane piston embedded in a rigid baffle and for small values of β coefficient, the acoustic potential ϕ at a point M, is given by [1]:

$$\phi(M,t)=v(t)\otimes\phi_i(M,t) \qquad (2)$$

where

$$\phi_i(M,t)=\iint_S \frac{e^{-\frac{(R-Ct)^2}{2\beta C^2 t}}}{(2\pi)^{3/2}\sqrt{\beta CtR}}\,dS \qquad (3)$$

represents the impulse response for the potential [1] and v(t) the velocity of the surface source, dS being an elementary surface centered around the point M_0 belonging to the source and $R=\left|\overrightarrow{MM_0}\right|$.

If the point M is on the axis of a circular transducer of radius a, the impulse response is :

$$\phi_i(z,t)=\frac{C}{2\sqrt{\pi}}\left\{\mathrm{Erf}\left[\frac{\sqrt{z^2+a^2}-Ct}{\sqrt{2\beta C^2 t}}\right]-\mathrm{Erf}\left[\frac{z-Ct}{\sqrt{2\beta C^2 t}}\right]\right\} \qquad (4)$$

If a rigid target of small surface S_C is placed in the acoustic field, the emitted wave is completely reflected and the average acoustic potential on the surface S_T of the transducer functioning now as a receiver is given by :

$$\langle\phi(t)\rangle=v(t)\otimes\frac{S_c}{S_T}\frac{\partial\phi_i}{\partial z}\otimes\phi_i \qquad (5)$$

For a weak attenuation, the detected average pressure can be written:

$$\langle p\rangle=\rho C\frac{S_C}{S_T}\frac{\partial v}{\partial t}\otimes\frac{\partial\phi_i}{\partial z}\otimes\phi_i \qquad (6)$$

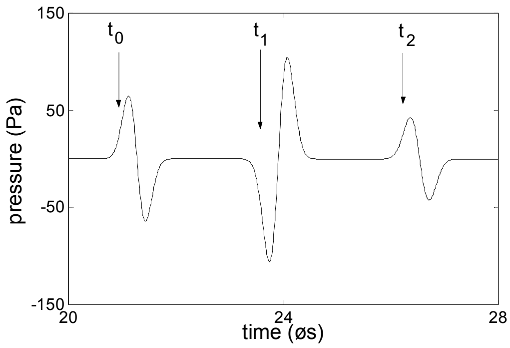

Figure 1 : Simulation of the detected pressure in the case of a circular transducer with a=10mm, and a circular target with a radius of 0.4mm; C=1.5mm/µs, z= 20mm, β=0.001 $mm^{-1}.MHz^{-2}$.

Figure 1 represents the detected pressure. This pressure consists of three impulses arriving at instants centered respectively on

- $t_0 = \frac{2z}{C}$
- $t_1 = \frac{\sqrt{z^2 + a^2} + z}{C}$
- $t_2 = 2\frac{\sqrt{z^2 + a^2}}{C}$

t_0 corresponds to a wave coming from the projection of the target on the surface of the transducer (direct wave or plane wave). t_1 represents the simultaneous arrival of two waves corresponding to a propagation from the center of the transducer towards the edge of the transducer and reciprocally. Finally t_2 corresponds to the arrival of a wave issuing from the transducer edge, reflected by the target towards the transducer edge. Because of the dispersion these arrival times correspond to mean values since they are preceded by precursors [1].

For two different positions z_1 and z_2, let us select the first impulse which corresponds to the direct wave and calculate the attenuation coefficient defined by

$$\alpha = \frac{1}{2(z_2 - z_1)} \mathrm{Log}\left[\frac{P_2(z_2;f)}{P_1(z_1;f)}\right] \qquad (7)$$

where $P_2(z_2;\, f)$ and $P_1\,(z_2;\, f)$ are respectively the spectrum of the first impulse of the three impulses detected when the target is on the transducer axis respectively at a distance z_2 and z_1. For a given value of β, it has been checked that the graph of α versus f^2 is a line whose slope is effectively equal to this value of β.

Principle of the method

An ultrasonic broad band transducer functioning in transmitting-receiving mode is used. The results obtained with a transducer with a diameter equal to 20 mm and a nominal frequency equal to 2.25 Mhz, and with a target which radius is 0.4mm are represented by Figure 2. The positioning of the target on the axis of the transducer is carried out by seeking the position for which the edge waves are of maximum amplitude.

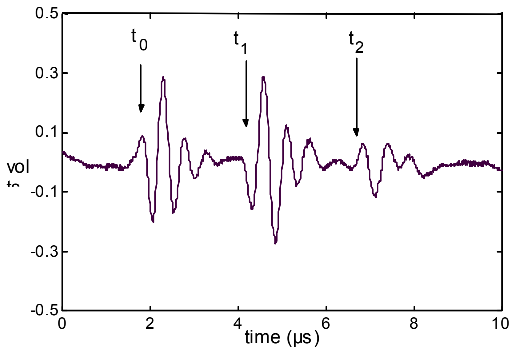

Figure 2: Echoes from the basis of a rod made of duralumin with a radius of 0.4mm, immersed in glycerine (C=1.92mm/µs)

The signal processing consists in reading the signals stored at two different positions, then to use the relation (7) to plot α versus f^2. The measurement of the slope of the linear interpolation of these results allows to calculate β. Figure 3 represents the results obtained with glycerine at a temperature T=16.8°C.

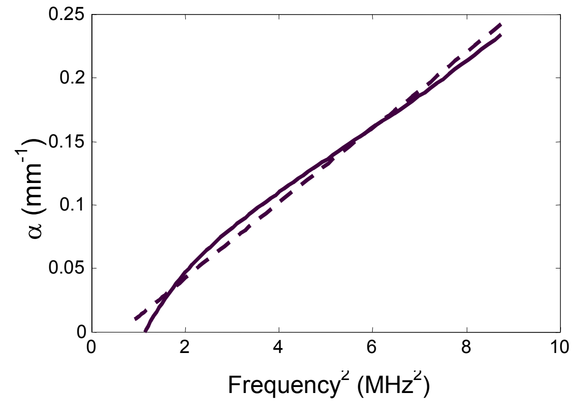

Figure 3 : Plot of α versus f^2. (___) : obtained from Equation (7); (- - -): obtained after a linear interpolation.

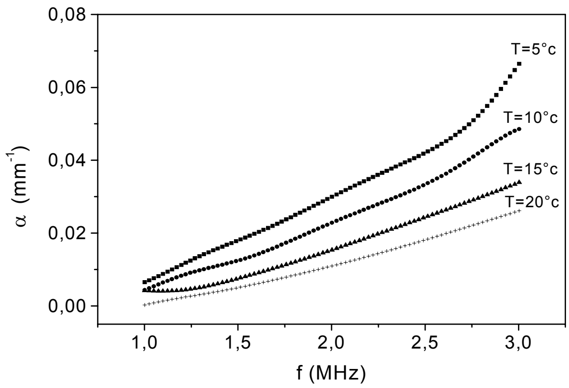

Figure 4 : Plot of α versus the frequency for paraffin oil at different temperatures.

This method has been used to study the variation of the ultrasonic attenuation versus the temperature for various viscous liquids like paraffin oil (Figure 4).

Conclusion

The principal advantage of this method is that the measurements are carried out in the field close to a plane transducer, thus avoiding the encountered problems of alignment when the measurements are made in the far field. This method can be used advantageously by replacing the reflectors by a broad band hydrophone of small size placed in the field near of the transmitter. In this case, the signal pressure is only made up of two pulses [2].

References

[1]. M.Deville et al., Proceedings of IEEE Ultrasonics Symposium, 1985, 683-687.

[2]. H.Djelouah et al.,Ultrasonics,**27**,80-85 (1989).