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ACOUSTIC MEASUREMENTS

RELATIVE MEASUREMENTS OF THE VELOCITY AND ATTENUATION OF ULTRASOUND IN HIGHLY ABSORBING LIQUIDS

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It is shown that it is possible to use a continuous sinusoidal signal to make relative measurements of the velocity and absorption coefficient of ultrasound in highly absorbing liquids such as liquid crystals. Compared with the traditional variable-frequency pulse-phase method, the technique described has the advantage of giving a direct reading of the results under dynamic measurement conditions. A block diagram and the characteristics of the equipment for measuring the anisotropy of acoustic parameters by both pulse and continuous methods are presented.

Measurement of small variations of acoustic parameters, for example, their anisotropy in liquid crystals, using the traditional variable-frequency pulse-phase method (particularly the modification proposed in [1]), is somewhat inconvenient despite its high stability and sensitivity. The main difficulties are the change in the working frequency due to the change in the velocity of ultrasound and the impossibility of making a direct readout of the results due to the need to maintain constant phase-amplitude balance between the probing and the reference signals. The latter imposes considerable limitations on the use of this method when working with objects whose properties change rapidly such as, for example, liquid crystals or magnetic liquids in pulsating and spatially alternating magnetic fields.

In addition, in strongly absorbing liquids such as liquid crystals, by an appropriate choice of the acoustic path length one can arrange for repeated reflections from the piezoelectric transducer to have a negligibly small effect on the resultant signal. As a result one can use a continuous sinusoidal signal of fixed frequency instead of probing radio pulses. We will illustrate this using the example of a typical acoustic chamber, described in [1]. At an operating frequency of 9 MHz the distance between the piezoelectric transducers amounted to 8 mm. We will assume that the amplitude of the first reflected radio pulse is 0.01 of the main signal. The absorption coefficient of the ultrasound in the medium being investigated should not be less than 3.6×10^{-12} sec^2/m. This condition is satisfied, for example, for a typical BBBA (butoxy–benzilidenebutyl–aniline) liquid crystal over the whole nematic phase. If we take into account that the attenuation of the reflected signals is due not only to absorption in the medium but also to scattering resulting, for example, from a lack of parallelism between the transmitting and receiving piezoelectric transducers, the above estimate can be even less rigorous. Hence, for this example, to a first approximation we can assume that the error in measuring the variations in the absorption coefficient due to repeated reflections does not exceed 1%. The error in measuring the variation in the phase of the received signal, i.e. the velocity of the ultrasound, can be estimated similarly; it has approximately the same value.

All the above assertions were verified on the equipment described in [2]. The ratio of the amplitudes and phase shifts of the initial and received signals in the acoustic chamber under continuous conditions were measured using the commercial FK2-12 instrument which has a phase resolving power of 0.2° and an amplitude sensitivity of 10 μV. A broadband low-noise amplifier included in the equipment was used to amplify the received signal.

Comparative measurements of the anisotropy of the velocity and the absorption coefficient of ultrasound by two methods show that they agree with one another with an error of not more than 5% for both parameters, which is less than for the pulse method.

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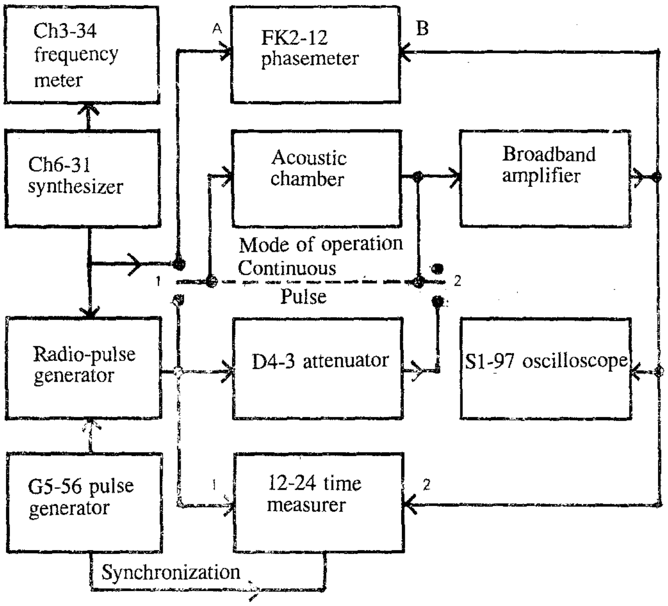

Fig. 1. Block diagram of the main part of the equipment.

In the method described the absorption anisotropy was calculated from the formula [2]

$$\Delta\alpha/f^2=\Delta D/(8{,}69df^2), \tag{1}$$

where f is the frequency of the sinusoidal probing signal, ΔD is the change in the amplitude of the received signal, dB, and d is the distance between the receiving and transmitting piezoelectric transducers.

The anisotropy of the velocity was calculated from the formula

$$\Delta c/c=\Delta\Phi(360/\tau-\Delta\Phi), \tag{2}$$

where c is the velocity of ultrasound, τ is the time taken for the ultrasound to pass through the specimen and $\Delta\Phi$ is the variation in the phase in degrees due to the anisotropy of the velocity.

In this case the phase resolution of 0.2° corresponds to a resolution of Δc/c of the order of 10^{-5}, which is approximately the same as the value obtained in the equipment being compared.

We will consider the ratio of the quantities in (2) for a typical situation [1]: measurements of the anisotropy of the velocity of ultrasound in the region of a phase transition (for example, from nematic to smectic A) in a BBBA liquid crystal. The anisotropy of the velocity in the nematic phase at a temperature which differs by 0.2 K from the transition temperature reaches 2×10^{-3}. This corresponds to a phase variation of the received signal of 40°, i.e. the error introduced by the phase measuring instrument amounts to 0.5%. The time taken for the ultrasound to propagate to the specimen was measured by a pulse method using an I2-24 instrument with a resolving power of 2 nsec. The error of the measurement is due mainly to the finite slope of the edges of the radio pulse. This error can be estimated to within one quarter of the filling period of the radio pulse, which in our case amounts to 27 nsec. In the acoustic chamber employed the time taken for the pulse to traverse the specimen is about 5.5 μs, i.e. the relative error of the measurements is approximately equal to 0.5%. The change in this time over a temperature range of 2 K does not exceed 0.25%. Hence, the error in determining the anisotropy of the velocity of ultrasound is not greater than 1%. Other sources of error were considered in [1, 2], but their contribution is much less. Moreover, the data given above show that it is quite unnecessary to measure the time τ for each change in the specimen temperature. It is sufficient to do this when the change in the velocity of the ultrasound exceeds, for example, half the random error of the phase meter. In our example these measurements only needed to be made when the temperature changed by 2 K.

One other observation needs to be made. It is obvious that under continuous conditions one must limit the amplitude of the probing signal so as to avoid any appreciable heating of the specimen. In the acoustic chamber employed this heating was observed if a voltage of more than 1 V was applied to the transmitting piezoelectric transducer. The volume of the specimen in the chamber was 10 ml. Quartz plates 20 mm in diameter were used as the piezoelectric transducers. Heating was noted from the change (reduction) in the velocity of the ultrasound after the signal was applied to the temperature-stabilized specimen.

A block diagram of the equipment which enabled the anisotropy of the velocity and the absorption coefficient of ultrasound to be measured under both pulsed and continuous conditions is shown in the Figure 1.

We will briefly consider its operation.

Under pulsed conditions the signal from the output of the radio-pulse generator [3] is applied simultaneously to the input of a D4-3 attenuator and the transmitting piezoelectric transducer in the acoustic chamber. The signal which has passed through the specimen is added to a reference signal from the attenuator output. By varying the frequency of the initial signal and the setting of the attenuator one can obtain amplitude-phase balance between the radio pulses – the reference pulse and the pulse which has passed through the specimen. From the values of the frequency and attenuation for different states of the specimen one can determine the change in the velocity and absorption coefficient of the ultrasound [1, 2].

Under continuous conditions a sinusoidal signal from the output of the frequency synthesizer is applied simultaneously to the transmitting piezoelectric transducer in the acoustic chamber and to the input A of the phasemeter. The signal which has passed through the specimen is amplified and applied to input B of the phasemeter. The FK2-12 instrument measures the variations in the phase difference and the ratio of the amplitudes of the received and reference signals for different states of the specimen. The corresponding values of the acoustic parameters are calculated from (1) and (2).

To measure this time taken for the radio pulse to pass through the specimen the switch 1 is moved to the lower position and the switch 2 to the upper position. The required time interval is then measured directly using the I2-24 instrument, supplied with an additional amplifier (not shown in the Figure 1).

The G5-56 rectangular video pulse generator controls the radio-pulse generator and synchronizes the operation of the time measurer and the oscilloscope.

In addition to the components shown in Figure 1, the equipment also contains a specimen thermostat, a system for reorienting it in a magnetic field, and a system for automating the measurements and processing the results using a microcomputer [4]. This equipment is a development of that described in [2] and was awarded a silver medal in 1989. The operating frequency range is 1-60 Mhz, and the resolving power when measuring the anisotropy of the velocity of ultrasound is 5×10^{-6} and when measuring the anisotropy of the absorption coefficient it is 10^{-14} $\sec^2/m$; the temperature of the specimen can be kept constant to within less than 0.001 K.

By combining the two methods in the new apparatus we can eliminate the drawbacks inherent in each of the methods employed and combine their advantages. Using the variable-frequency pulse-phase method [1, 2] one can make measurements under static conditions with increased resolving power and with long-term stability. The continuous-signal method is best used under dynamic conditions to measure rapidly varying acoustic parameters of the specimen. This equipment, together with a similar one designed to operate in the 0.15-1.2 MHz frequency band [5], can be used for acoustic investigations of phase transitions in liquid crystals.

The equipment was developed and manufactured at the Moscow Institute of Instrument Construction and at the Laboratory for Molecular Acoustics Problems.

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