AUTOMATIC MEASURING ARRANGEMENT FOR THE ACOUSTIC PARAMETERS OF ANISOTROPIC LIQUIDS

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The arrangement makes it possible to measure in liquid crystals, magnetic liquids, etc., oriented in a magnetic field, the anisotropy of ultrasonic velocity with a relative resolution of $5 \cdot 10^{-6}$, and the anisotropy of the absorption coefficient with a resolution of $1 \cdot 10^{-14}$ $sec^2 \cdot m^{-1}$ at frequencies from 1 to 30 MHz, and also the absolute velocity of ultrasound with an error of no more than 0.3%. The very stable temperature maintenance of 0.001 K in a specimen makes this arrangement particularly effective for studying liquid crystals in the region of polymorphic transformations. The operating principle of the arrangement is based on a modified pulse-phase, variable frequency method proposed by the author, which is characterized by a high resolution and which takes into account the error introduced by frequency dependent phase shift in the piezoelectric transducers [1].

A block diagram of the arrangement is shown in Fig. 1, where 1 is a type Ch6-31 frequency synthesizer; 2 is a type I2-24 time-interval indicator; 3 is an amplifier-shaper for radio-frequency pulses [2]; 4 and 6 are commutators; 5 is a measuring chamber with a set of piezoelectric transducers; 7 is a band-pass amplifier; 8 is a type S1-97 oscilloscope; 9 is a type G5-56 rectangular-pulse generator; 10 is a type D4-3 attenuator; 11 is a switch; 12 is a photoelectric digital sensor; 13 is a programmable temperature control [3]; 14 is a type DSh-0.25 A step-by-step electric motor; 15 is a controller for the step-by-step electric motor; 16 is a turning device for the chamber; 17 is a quartz thermometer [4]; 18 is a type F5041 frequency meter; 19 is a type 15 IÉ 200 × 170 display; 20 is a type UVVPCh-30-004 printer; 21 is an Élektronika D3-28 computer; 22 is a coupling arrangement with the objects (CA).

The measuring chamber 5 contains several pairs of switchable, quartz piezoelectric transducers which span the required frequency range. The distance between the piezoelectric transducers is between 4 and 40 mm, and their diameter is 6 to 20 mm, depending on the frequency. The chamber is fabricated from type Kh17N13M nonmagnetic stainless steel and is located between the cores of an electromagnet having an induction up to 0.6 T on a rotating device that makes it possible to change the angle between the wave vector and the vector of the magnetic induction over a range from 0 to 360°. A sinusoidal voltage from a frequency synthesizer 1 is fed to the amplifier-shaper for radio-frequency pulses 3 [2] that is controlled by the rectangular-pulse generator 9. From the output of the amplifier-shaper the radio-frequency pulses go to the attenuator 10, which is of the cut-off type, and through the commutator 4 to a chosen piezoelectric transducer in the chamber 5. The duration of a pulse from the generator 9 is determined according to the time overlapping condition of the radio-frequency pulses passing through the chamber and the attenuator. These are summed on the input of the band-pass filter 7, which has a switchable gain and a resonant frequency.

By changing the frequency at the synthesizer's output and the loss introduced by the attenuator, the resultant signal observed on the screen of the oscilloscope 8 is made equal to zero. In this case the signals that pass through the measuring chamber and attenuator are equal in amplitude and of opposite phase. When there is a change in the acoustic parameters of an object, i.e., in the velocity and the absorption coefficient of the ultrasound, the frequency at the synthesizer's output and the loss introduced by the attenuator, which are required to maintain the zero value of the resulting signal, are altered. From these data the changes in the velocity $\Delta c/c$ and in the absorption coefficient $\Delta\alpha/f^2$ of the ultrasound are calculated from the following formulas [1]:

$$\frac{\Delta c}{c} = \frac{\Delta f}{f\tau}(f_2 - f_1)^{-1}; \quad (1)$$

$$\Delta\alpha/f^2 = \Delta D/(8.69 df^2). \quad (2)$$

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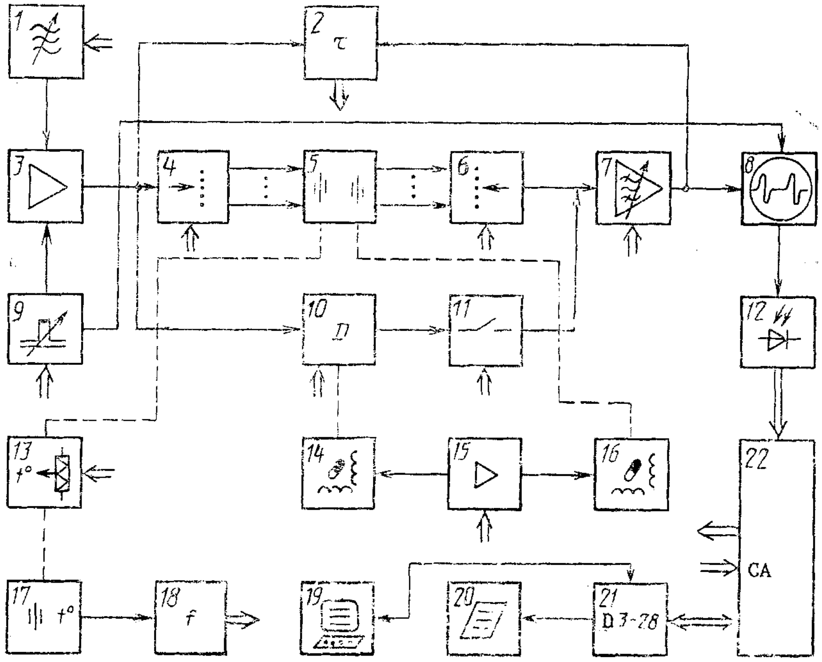

Fig. 1

Here f is the frequency of the synthesizer's sinusoidal signal and Δf is its change; τ is the transit time for the radio-frequency pulses through a specimen; f_1 and f_2 are frequencies that correspond to two adjacent minima in the resulting signal; ΔD is change in the attenuator's loss, in dB; d is the distance between the receiving and transmitting piezoelectric transducers.

The time interval τ is determined with the switch 11 open by means of the time-interval indicator that has a resolution of 2 nsec. The receiving electrode of the attenuator 10 is shifted by means of a reducer with the step-by-step electric motor 14, which the computer controls through a special controller 15. Thus it is possible by means of a program to set the attenuator's loss to within 0.02 dB. A similar motor is used in the turning device 16 and is capable of orienting the measuring chamber in the magnetic field with an error of no more than 0.3°.

The temperature of an object is regulated by a double thermostat based on the proposal in [3]. The object's temperature is measured by means of an electronic temperature-frequency transucer based on a quartz resonator [4] together with the frequency meter 18.

Information is read from the oscillograph's screen by means of the photoelectric sensor (PES) 12, consisting of a matrix with 32 × 1 type FD—6G photodiodes. The sensor is positioned vertically in the middle of the oscilloscope's screen, covering a large portion of the image. Thus the number of photodiodes that are illuminated is proportional to the spread of the signal on this screen. The digital code obtained from the PES is utilized as a control parameter in a feedback network that maintains a phase and amplitude balance for the signals passing through the acoustic chamber and attenuator.

It should be emphasized that the zero-method discussed above for maintaining the phase-amplitude balance of the radio-frequency pulses by utilizing a discrete photoelectric sensor is substantially more resistant to destabilizing factors, let us say, than a similar system that uses a phase detector and an amplitude comparator. In the final analysis this improves the resolution and measuring accuracy of the arrangement; as for a phase detector, it is practically impossible to realize one with acceptable characteristics. Also, an amplitude comparator is very susceptible to interference as well as temperature fluctuations so that the parameters of the arrangement would be substantially reduced.

Let us consider the possible sources of measuring errors. First of all it must be noted that the typical dimensions of the acoustic chamber (the distance between piezoelectric transducers and their diameter) were chosen to be at least twice the greatest corresponding wavelength. This, as is well known [5], practically eliminates the effect of diffraction and interference of the sound waves on a measurement of the sound velocity for the accuracy indicated at the beginning of the article. The same holds for a measurement of anisotropy on the ultrasonic absorption coefficient. The use of nonmagnetic materials in the fabrication of the chamber ensures the absence of its distortion in the magnetic field, which is confirmed by check measurements in isotropic liquids.

The limit of the method's sensitivity (resolution) and the change in the velocity and the absorption coefficient of ultrasound is limited by the system's interference (by noise, nonlinear distortions and parasitic modulation of the signal), which reduces the accuracy with which the sum of pulses that pass through the measuring chamber and the attenuator is equated to zero. The error of a frequency setting was 50 Hz at a measuring frequency of 10 MHz, and the attenuator's readings were set with an error of 0.04 dB. With these values, the changes of frequency and attenuation were adopted for which, with a probability of 0.98, the minimal level was noted for the resulting signal picked up by the PES from the oscilloscope's screen. All the information above serves as a basic evaluation of the arrangement's resolution.

We shall now continue with the description of the arrangement. In order to simplify the nonstandard units and to improve the operating quality of the arrangement overall, software was written for a negative-feedback algorithm that maintains a phase-amplitude balance in accord with the method's concept. For this purpose a microcomputer was included in the makeup of the measuring system. Its use substantially speeds up, by raising to a new level of quality, the investigations of how the acoustic parameters depend on the angle between the wave vector and the induction vector with changing temperature and frequency in the most interesting regions of the phase transitions for liquid crystals.

The basic functions of the microcomputer can be allotted in the following way: control of the standard peripheral equipment such as the display and the printer; control through the coupling arrangement (CA) of the nonstandard (for the computer) instruments such as the synthesizer, the temperature control, the commutators, etc.; reading through the CA the information from the various measuring instruments such as the frequency meter, the voltmeter, the time-interval indicator, the photoelectric sensor (on the oscilloscope), etc.; primary processing of the information in accord with the algorithm of the method being employed; secondary processing of the data in accord with the theoretical assumptions adopted (some of the levels or stages of the calculations); documentation of the required initial, intermediate, and final data. It is evident that the effective realization of the functions listed requires an optimal combination of equipment and programming means, which have been developed with due regard for the characteristics of the equipment employed and for the mathematical aspects of the task.

The specially developed CA includes multiplexers, decoders, memory registers, and switches by means of which information drawn from the computer is converted into signals that are responsible for the operating characteristics of particular devices, and vice versa. In order to simplify the CA's design, most of the conversions are performed in the computer in accord with the programs.

The system software is based on an interpreter of the BASIC language, a version supplemented by matrix and certain other operators. For the input and output of information through the CA, the interpreter is augmented by auxiliary programming in machine codes having a total volume of about 1 kilobyte. The programs written in the BASIC language specify the conditions of the experiment, realize the measuring method employed, and provide the special treatment of the data obtained.

The use of the BASIC-interpreter makes it possible when necessary to alter operationally the course of an experiment and the data-processing program for acceptable time characteristics of the system.

The algorithm for the system operation when measuring the temperature-frequency functions for the anisotropy of the acoustic parameters of liquid crystals includes the following operations:

1. Start
2. Input of initial data: frequency ranges, interval and step of temperature measurement.
3. Has the object's temperature been established? If not, then go to step 3.
4. Set the required angle of orientation for the object in the magnetic field.
5. Set the required frequency range.
6. Change the frequency and attenuation in succession.
7. Has the resultant signal reached a minimum? If not, go to step 6.

8. Clamp the frequency and attenuation.
9. Has the frequency range been exhausted? If not, go to step 5.
10. Has the recording of the angular function been completed? If not, go to step 4.
11. Has the temperature range been exhausted? If yes, go to step 15.
12. Set the next temperature.
13. Process the data.
14. Read out information about the course of the experiment. Return to step 3.
15. Process the set of data obtained.
16. Read out the experimental results.
17. Finish.

The automatic arrangement was developed in the Problem Laboratory of Molecular Acoustics at the Moscow Institute of Instrument Construction and is being used for acoustic studies on the molecular-kinetic properties of liquid crystals.

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