ВИМІРЮВАННЯ АКУСТИЧНИХ ВЕЛИЧИН
MEASUREMENT OF ACOUSTIC QUANTITIES

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Immersion ultrasonic transducers

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Abstract

The principles of operation and design of immersion ultrasonic transducers developed by the authors for excitation and reception of elastic vibrations in moving filament-like and plane-parallel materials, in particular, polymer fibbers and films, with an adjustable angle of input (reception) of probing signals into moving controlled object – polymer fibbers and films at normal and high temperatures.

The technical characteristics of the installation are given in which the converters developed by us are used, namely, sounding base (distance from the emitter to the receivers), the duration of the probing pulses, the frequency of filling and the duration of the probing pulses, the speed of the controlled object, the combined standard measurement uncertainties of the difference Δt of the propagation times of ultrasonic waves from the emitter to the first and second signal receivers, relative combined standard uncertainties of measurements of attenuation coefficient and velocity of propagation of ultrasonic waves.

Keywords: immersion; ultrasonic; transducer; fiber; uncertainty.

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1. Introduction

Quality control of polymer films and fibers (hereinafter referred to as the material) directly in the process of their production is one of the urgent technological problems. It is due to the fact that the physical, mechanical and strength properties of the material strongly depend on the technological regime, and express measurements of the acoustic characteristics (velocity of propagation and the attenuation coefficient of ultrasound) of the material, which are related to its elastic and strength properties, make it possible to quickly control the technological regime. To measure the acoustic characteristics of materials, special ultrasonic transducers (emitter and receiver) are used.

Transducers used to emit and receive ultrasound in a stationary material are not suitable for moving materials. The main reason for this is the excitation of a noise signal in the receiving transducer, the level of which is several times higher than the level of the useful signal. The existing transducers for the control of moving materials have not found wide application for certain reasons. For this purpose, we have developed a number of ultrasound transducers [1–3].

2. Statement of the problem and analysis of the literature

Ultrasonic quality control of continuously moving filaments and films is carried out, as a rule, according to the measured values of the propagation velocity and the attenuation coefficient of ultrasound in these objects. The most common and more acceptable method for measuring the propagation velocity and the attenuation coefficient of ultrasound in continuously moving objects is a pulsed one. The device [4–8] is based on the impulse method for measuring the propagation velocity and the attenuation coefficient of ultrasound.

The objectives of this article were the study of technical issues of effective excitation and reception of elastic vibrations in moving thread-like and plane-parallel materials, in particular, polymer fibers and films.

3. Presentation of the main material

Immersion ultrasonic transducers for excitation and reception of elastic vibrations in moving materials have been developed in three versions:

a) with a constant angle of input (reception) of ultrasonic sounding signals into the controlled object (hereinafter – the angle);

b) with an adjustable angle at low temperatures (Fig. 1);

c) with an adjustable angle at high temperatures (Fig. 2).

Studies have shown that the main drawback of the transducer design [1] is the fixed angle ($\beta_1 = 0$) of wave incidence on the surface of the controlled

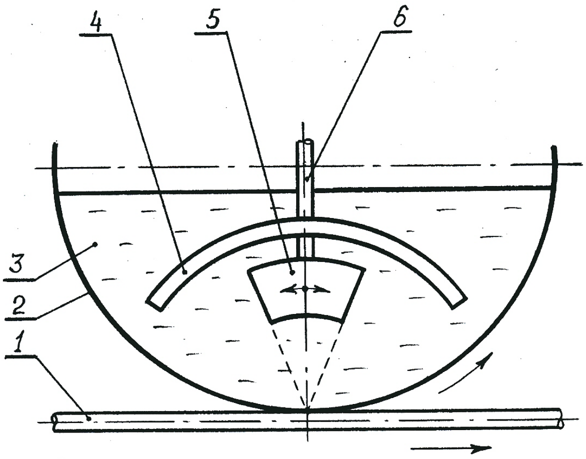

Fig. 1. Variable angle immersion ultrasonic transducer for use at low temperatures: 1 – controlled object; 2 – rotating cylindrical body; 3 – immersion liquid; 4 – guide for adjusting the angle of input (reception) of probing signals; 5 – focusing piezoelectric element; 6 – piezoelectric element holder [3]

sample, which limits its functionality. The ability to vary the angle of incidence will effectively excite vibrations in the samples under study. Changing the angle of ultrasound input is achieved by changing the angular position of the focusing piezoelectric element 5 (Fig. 1 and Fig. 2) by changing the position of the holder 6 of the piezoelectric element on the arcuate guide 4 of the rotation and movement mechanism. The focusing piezoelectric element 5, together with the mechanism of its movement along its own acoustic axis, makes it possible to concentrate ultrasonic vibrations on the surface or inside the controlled object 1 both in the form of a point (for threads and fibers) and in the form of a transverse line (for films).

Thus, it is possible to introduce ultrasonic vibrations into a moving controlled object at various angles β ($0 \leqslant \beta \leqslant 90$ °). For example, if a wave from a liquid falls on the boundary with the inner surface of the body normally ($\beta_1 = 0$), then it passes (refracts) into the body, and then into the controlled object at the same angle, i.e. $\beta = \beta_2 = \beta_1 = 0$ (where β_2 and β are the angles of wave refraction in the transducer housing and the controlled object). In this case, transverse vibrations of the object are effectively excited, similar to the transverse vibrations of a string. If the wave falls obliquely at a certain angle $\beta_1 \neq 0$, then the angle of refraction of the wave in the object β, according to the law of refraction of elastic waves, is determined by the dependence:

$$\sin\beta = \frac{c}{c_1}\sin\beta_1,$$

where c_1 and c are the velocities of wave propagation in the fluid and the controlled object. For example, it was observed that if an ultrasonic wave from water ($c_1 = 1490$ m/s) falls at an angle $\beta_1 = 44.5°$, then the angle of refraction in a controlled polyethylene terephthalate film ($c = 2125$ m/s) is 88°, i.e. the direction of wave propagation practically coincides with the longitudinal axis of the object, which leads to the most efficient excitation of waves of the longitudinal mode in it.

To reduce the level of reverberation noise of the transducer caused by multiple reflections of probing ultrasonic waves, the inner surface of its cylindrical body is pasted over with special damping rubber (excluding the zone for the passage of working acoustic signals), which simultaneously dampens natural vibrations (vibrations) of the transducer and, as a consequence, decreases the level parasitic low-frequency vibrations.

When inspecting the material, the shaft of the rotating cylindrical transducer, as well as the piezoelectric element installed on it, remain stationary, thereby achieving a stable amplitude of the wave excited in the controlled object. In order to efficiently transmit ultrasound from the focusing piezoelement 5 through the immersion liquid layer 3 and the cylindrical body 2 to the controlled material 1, it is desirable to make the case 2 of a material with an acoustic impedance close to the acoustic impedance of the material under test.

Studies have shown that for all its advantages, the converter described above also has a significant disadvantage in the form of a technological limitation on its use at high temperatures. The reason for this limitation is associated with the fact that the maximum permissible operating temperature of the bulk of the piezoelectric elements used in ultrasonic transducers does not exceed 100 ÷ 300 °C, depending on the brand of piezoelectric material used for their manufacture.

Specifically, in order to be able to control the acoustic characteristics of moving materials at high temperatures, a different design of the immersion transducer was developed (Fig. 2), in which the performance of the piezoelectric element 5 from the effects of high temperatures is protected by a special thermal

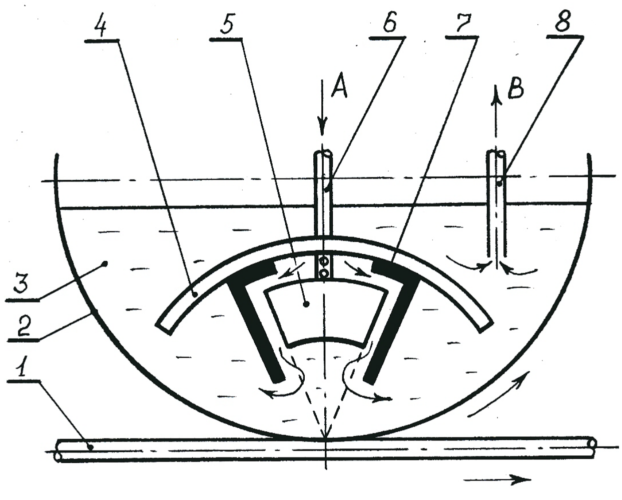

Fig. 2. Variable angle immersion ultrasonic transducer for high temperature applications: 1 – controlled object; 2 – rotating cylindrical body; 3 – immersion liquid; 4 – guide for adjusting the angle of input (reception) of probing signals; 5 – focusing piezoelectric element; 6 – piezoelectric element holder; 7 – thermal insulation casing of the piezoelectric element; 8 – branch pipe for intake of immersion liquid for its cooling; A – inlet, B – outlet of the cooling immersion liquid [3]

Table 1

Technical and metrological characteristics of the installation in which the converters developed by us are used

Sounding base (distance from emitter to receivers), m	0.15÷1
Controlled object thickness, m	$5\times10^{-5}\div2\times10^{-3}$
Probing pulse filling frequency, Hz	$2\times10^{4}\div10^{5}$
Probing pulse repetition rate, Hz	$5\times10^{2}\div10^{3}$
Duration of probing pulses, s	$5\times10^{-6}\div10^{-4}$
Controlled object speed, m/s	0 ÷ 5
Combined standard uncertainty in measuring the difference Δt in the propagation times of the USW from the emitter to the first and second signal receivers, μs	1.4
The combined standard uncertainty of measuring the difference ΔL of the distances between the emitter and the first and second receivers, mm, not more	1.8
Relative combined standard uncertainty of damping coefficient α measurement, no more, %	10
Relative combined standard uncertainty in measuring the propagation velocity of RAS, no more,%	1

insulating casing 7 and a “jacket” cooling immersion liquid. Optimal, from the point of view of the operability of such a converter, will be the mode when the temperature of the piezoelectric element 5 is in the operating range (for example, 20 °C), the operating temperature of the monitored object 1 and the cylindrical body 2 of the transducer are equal (for example, 200 °C), and the temperature change the layer of immersion liquid 3 along the path of the probing signals from the piezoelectric element 5 to the housing 2 is maintained at their respective temperatures (from 20 °C to 200 °C).

It should be noted that it is impossible to cool the entire immersion liquid (transducer housing) to the operating temperature of the piezoelectric element in order to exclude the possibility of the transducer's temperature influence on the controlled object. The optimal mode is easy to maintain by partial intake (flow B) of immersion liquid 3 and its subsequent return (flow A) through the holder 6 into the housing 2 of the converter after it has been cooled (thermostated). In this case, a “jacket” of cooling of the piezoelectric element 5 appears inside the thermal insulation casing 7, the efficiency of which can be controlled by changing the flow rate of the cooling immersion liquid and its cooling temperature.

The technical and metrological characteristics of the installation in which the converters developed by us are used are presented in Table 1.

It follows from Table 1 that the relative combined standard uncertainties of the measurement of the attenuation coefficient α and the propagation velocity of the RAS, respectively, are not more than 10 and 1%.

4. Conclusions

To excite and receive elastic vibrations in moving thread-like and plane-parallel materials, in particular polymer fibers and films, it is advisable to use immersion ultrasonic transducers.

Transducers with an adjustable angle of input and reception of probing signals in a moving controlled object have many advantages over transducers with a constant angle of input and output.

The main source influencing the combined standard uncertainties of measurement of the attenuation coefficient α of RAS is the standard measurement uncertainty.

Імерсійні ультразвукові перетворювачі

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Анотація

Розглянуто принципи роботи і конструкції розроблених авторами імерсійних ультразвукових перетворювачів для збудження і прийому пружних коливань у рухомих ниткоподібних і плоскопаралельних матеріалах, зокрема полімерних волокнах і плівках, із можливістю регулювання кута введення (прийому) зондувальних сигналів у рухомий контрольований об'єкт – полімерні волокна і плівки при нормальних і високих температурах.

Показано основний недолік конструкції існуючих перетворювачів, що обмежує їхні функціональні можливості. Досліджено технічні питання ефективного збудження і прийому пружних коливань у рухомих ниткоподібних і плівкових полімерних матеріалах. Надано два варіанти імерсійних ультразвукових перетворювачів із можливістю регулювання кута падіння в межах від нуля до 90 градусів для використання при відносно низьких і високих температурах. Показано умови (кути падіння хвилі) найбільш ефективного збудження в контрольованому об'єкті хвиль поздовжньої та (або) поперечної моди. З метою ефективного передавання ультразвуку від перетворювача до контрольованого об'єкта запропоновано циліндричний корпус перетворювача виготовити з матеріалу з акустичним імпедансом, близьким до акустичного імпедансу контрольованого об'єкта.

Наведено технічні та метрологічні характеристики установки, в якій використано розроблені нами перетворювачі, а саме: база проникання (відстань від випромінювача до приймачів), тривалість зондувальних імпульсів, частота заповнення і тривалість зондувальних імпульсів, швидкість руху контрольованого об'єкта, сумарні стандартні невизначеності вимірювань різниці Δt часів поширення ультразвукових хвиль від випромінювача до першого і другого приймачів сигналів, відносні сумарні стандартні невизначеності вимірювань коефіцієнта загасання і швидкості поширення ультразвукових хвиль.

Ключові слова: імерсійний; ультразвуковий; перетворювач; волокна; невизначеність.

Иммерсионные ультразвуковые преобразователи

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Аннотация

Рассмотрены принципы работы и конструкции разработанных авторами иммерсионных ультразвуковых преобразователей для возбуждения и приема упругих колебаний в движущихся нитеподобных и плоскопараллельных материалах, в частности полимерных волокнах и пленках, с регулируемым углом ввода (приема) зондирующих сигналов в движущийся контролируемый объект – полимерные волокна и пленки при нормальных и высоких температурах.

Приведены технические и метрологические характеристики установки, в которой использованы разработанные нами преобразователи, а именно: база прозвучивания (расстояние от излучателя до приемников), длительность зондирующих импульсов, частота заполнения и длительность зондирующих импульсов, скорость движения контролируемого объекта, суммарные стандартные неопределенности измерений разности Δt времен распространения ультразвуковых волн от излучателя к первому и второму приемникам сигналов, относительные суммарные стандартные неопределенности измерений коэффициента затухания и скорости распространения ультразвуковых волн.

Ключевые слова: иммерсионный; ультразвуковой; преобразователь; волокна; неопределенность.

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