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Ultrasonic method of quality control for textile materials

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ABSTRACT

Purpose: The ultrasonic amplitude method for controlling the surface texture density of textile materials was first studied and used.

Design/methodology/approach: For the first time, the surface texture density has been determined. The research was conducted using the ultrasonic method, rather than by mathematical calculations, which made it possible to invent a new approach to contactless quality control of textile materials. In order to identify the functionality of bicomponent textile material, formed from raw materials with opposite hygroscopic properties, two-layer knitted fabrics were chosen to protect the human respiratory organs. As a hydrophilic type of raw material used yarn with composition is as follows – cotton 34%, flax 33%, viscose 33%, and in the function of a hydrophobic raw material, polypropylene multifilament yarn. Using the ultrasonic method, studies of a new type of knitwear were carried out, the values of the surface density of the material were obtained. Products from this composition provide respiratory protection from dust and comfortable work in the area of road repairs up to 8 hours.

Findings: The combination of natural and synthetic materials for individual masks allowed them to be used under different operating conditions. The problem of structure and design of materials was resolved through the use of computer technology and computer-aided design of textiles, and the possibility of applying the ultrasonic amplitude method to control the surface density of textile materials was substantiated. During the analysis of the results of experimental studies, it was found necessary to ensure the uniformity of the physical and mechanical properties of textile materials in the production process. Using the ultrasonic method, the thickness gauge was used to determine the surface density of various materials for the manufacture of personal protective equipment for road maintenance workers.

Research limitations/implications: The method of measurement has been tested and has no limitations. However, the study was conducted on samples of textile materials that were manufactured in Ukraine and according to patents of authors.

Practical implications: Individual masks for the protection of human respiratory organs are recommended for use by road workers and cyclists.

Originality/value: The originality of the results of the article is the experimental data of studies on the content of textile materials and the accuracy of measuring their surface density by an ultrasonic contactless device.

Keywords: Control, Quality, Textile materials, Ultrasonic method

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Contamination of the air with emissions from industrial plants and motorcar exhaust gases inflicts incorrigible injuries to human health. The insufficient assortment of respirators and the scarce information about the methods of respiratory protection cause frequent diseases of organs of breathing.

Today the consumer does not have a sufficient opportunity to choose a respiratory protection, although there is a growing demand for this product.

The consumer properties of human protection depend to a great extent on the materials and the technology of their production.

For example, work [1] performs dimensionality reduction-based classification on fleece fabric-based images taken by a thermal camera. The experimental results showed that combined work has a great classification accuracy. Study [2] shows that fabric defects have been detected and classified from a video recording captured during the quality control process. In paper [3], a new method based on the use of thermal camera for detecting these defects from the textile fabric images is presented.

As a result of universal industrialization, during the last 200 years there was violated the proportional composition of gases, which is necessary for a balanced atmosphere. The burning of fossil fuels resulted in huge emissions of carbon dioxide and other gases, especially after the appearance of cars in the end of the nineteenth century.

Clean air is a key to good health. It is known that air consists of oxygen (O_2) and nitrogen (N_2) in the correlation of approximately 1:3. In the quiet state a person breathes in about 10 litres of air per minute. However, the air that a person breathes in may contain an enormous amount of dangerous substances [4].

The dangerous substances can be presented in the form of solid or liquid aerosol particles, gases, vapours or evaporations. The smaller is the size of dust particles, the longer they are in the air in the suspended state and the higher is the probability that they will get inside with the air and penetrate into the lungs. Fog consists of microdrops that appear when different liquid materials are sprayed. Being inhaled, small solid or liquid particles cause the irritation of the upper respiratory airways and in case of a prolonged influence they cause an inflammation. Very dangerous are tiny dispersed particles of toxic dust that are capable of getting into the lungs and, having a very large area of contact with the tissue of the lungs, can be quickly and in great numbers sucked in, causing an intoxication of the organism [4].

At mixing many contaminants produce an irritating effect on the respiratory system. Masks help to prevent many dangerous diseases, as it is known that such substances as pyrene and benzol that are contained in exhaust gases are oncogenic.

It is impossible to see vapours and gases even when they have very large concentrations. Unlike solid and liquid aerosol particles, the organism practically does not resist the influence of gases and vapours. When breathed in, vapours and gases get directly into the lungs and already from there they get into the blood circulation system without any difficulty. Passing through the blood circulation system, they do harm to the internal organs and the brain [4].

Gases can be subdivided on the basis of their influence on the human organism: simple asfixants such as, for example, methane, carbon dioxide and helium, substitute the level of oxygen in the air, causing anoxia; chemical asfixants, for example, hydrogen cyanide, carbon monoxide and hydrogen sulphide influence on the process of absorption of oxygen and cause anoxemia of the tissues of the body.

Irritating gases usually have a strong smell, they can cause irritation of the eyes and a strong irritation of mucous membrane of the upper respiratory tract.

Having penetrated into the lungs, particles of untoxic dust can stay there for a long time. Around every dust particle gradually overgrows connective tissue that is already unable to participate in the process of gas exchange of the organism.

The process of overgrowing of connective tissue is slow, as a rule it takes many years. Having overgrown, the connective tissue substitutes a considerable area of pulmonary tissue. As a result, the person does not have enough oxygen for even a slight physical activity: he is short of breath when he tries to walk faster or when he tries to make a physical effort of average complexity. A prolonged lack of oxygen results in weakening the organism, decline of physical capacity and resistibility of the organism to the infectious and other diseases, changes of the functional state of organs and systems of the organism. The influence of dust on the respiratory system causes specific diseases, the so-called pneumoconiosis [4,5].

In order to provide adequate respiratory protection of a person, it is necessary to have information about the composition and concentrations of dangerous contaminants in the air, as well as to clearly understand the purpose and restrictions in the use of means of respiratory protection. We must consider such factors as the condition of the user, the degree of his physical exertion, the time spent in the contaminated area, need for freedom of movement, temperature and humidity of the air, the individual characteristics of the user, the possibility of servicing remedies. Non-replaceable ant aerosol respirators are made fully or for a greater part from a filter material and may have a valve of exhalation. Requirements to such respirators are expounded in the standard of DSTU EN 149:2003. They can have the following marking: FFP1, FFP2 or FFP3 [5,7-10].

Masks and half-masks with replaceable filter elements cover the forehead, the nose, the mouth and the chin of the user. The requirements for masks are set out in the standard DSTU EN 136:2003. Masks and half-masks should fit the user's face. Requirements for anti-aerosol filters that can be applied with masks and half-masks are set out in the standard DSTU EN 143:2002. Requirements for anti-gas and combined filters are described in the standard DSTU EN 141:2001. Anti-aerosol filters can be marked P1, P2 or P3 depending on filtration efficiency. Gas filters are marked with a corresponding colour code and number that indicates the class of the filter (1, 2, 3) depending on the capacity of the filter [4,5].

The most common means of filtering gases or vapours is activated charcoal that has a huge inner surface and is capable of retaining molecules of organic vapours. In order to retain molecules of inorganic or acid gases, or ammonia activated carbon is subjected to an appropriate chemical treatment [4,5].

Filter elements with activated carbon that do not have indicators of validity should be applied to protect only against the gases or vapours that have strong identifying characteristics (the ability to determine by the smell or by the taste at certain concentrations in the air). Filters to protect against gases or vapours are marked with the letters A, B, E, and K. (A – protection against organic vapours; B – protection against nonorganic vapours; E – protection against acid gases; K – protection against ammonia and its organic derivatives) and also with a corresponding colour code and a figure that indicates the class of the filter (1, 2, 3) depending on its capacity.

If the air contains gases or vapours as well as solid or liquid aerosol particles, it is necessary to use combined filter elements.

All anti-aerosol filter elements and respirators function up to the moment when breathing becomes difficult. The time of the work of gas filters should be limited to the appearance of odour or taste of the substance against which the gas respirator protects. A good practice is a preliminary calculation of the working time of gas filters and their replace before they break. The filter elements cannot be cleaned and re-used [4,5].

The principle of operation of any respirator consists in automatic trimming off the dust and applying an electrostatic charge that helps detain small particles.

At present an economic option of protection of respiratory organs of man are masks made of neoprene. Neoprene is a foamed polymer with closed cells filled with air, made in the form of fabric. The rubber fabric can be two-component consisting of foamed neoprene and another polymer of a solid structure. On the surface of the rubber on one or two sides a woven or knitted basis of nylon, polyester or cotton is glued. Generally, fabric or textile is used. The main component of neoprene is polychloroprene, a polymer of chloroprene.

Depending on what properties of the product are desired, in the composition of neoprene are included additives, for example sulfur or other polymers, for example ethylene-propylene-diene-monomer. The neoprene coating provides a sealed connection to the face and serves as a frame for the filter. Most commonly used is a carbon filter. If neoprene fabric is used as the material for the mask, masks have some disadvantages: this kind of fabric does not let in air and water. It has low water absorption – less than 2% of its own weight. Consequently, the mask becomes uncomfortable in case of a high degree of physical activity. At present there are being developed modifications of neoprene that have microscopic air holes, i.e. the material is breathable.

There also exist plastic masks. The basis of such masks is statically charged fibres. Plastic masks can be washed and worn for years, but they have some drawbacks. As the mask does not fit your face hermetically you distinctly feel the smoke. Besides the skin on your face is drawn into the mask, and the trace is for 10 minutes after you take it off.

Due to the insufficient study of the problem, lack of materials, absence of a sufficient number of specialists in this area, only a few companies in the world produce means for the protection of cyclists, especially those with changeable filters. The most common types of filters are made of environmentally friendly and high-tech materials such as statically charged fibres that retain the micro-particles and have activated carbon as an additive in their weave that cleans the air of toxic gases. In the design of sports filters there are valves that allow to safeguard the respiratory organs from carbon dioxide and wet vapour. For a person who works in a contaminated environment, it is important that the respirator should be well fixed on the face and should not interfere with breathing.

Polluted environment requires the solution of the problem of human protection with the help of modern means of protection using available materials that guarantee the quality of detaining dust particles, not getting them to the human respiratory system.

As materials we selected textile materials, namely fabrics and knitted fabrics of various raw materials. The quality control of textile materials is sufficiently substantiated in many scientific papers. Among them are known monographs, textbooks, tutorials that were written many years ago and modern publications. The scientific works of scientists [6-15] were analysed in detail for the most substantiated disclosure of the topic.

Due to the topicality of diseases of the human respiratory tract, we studied the works of leading scientists concerning the causes and methods of avoiding respiratory inflammation. Also, there was made an analysis of the range of protective masks for sports and domestic destination.

Major functions of respiratory protection can be achieved by using a certain thickness of the fabric, by combining materials, by using a multilayer structure [6,8,10-14]. Recently there arose the question of developing multifunctional textile materials, whose layers would have diametrically opposite properties. There are several ways of obtaining the desired result, namely: 1) combination of materials with different properties in the process of weaving or knitting; 2) creation of multifunctional multilayer composition textile material whose layers are made from raw materials with different properties.

In order to identify the functionality of bi-component textile material formed from raw materials with opposite hygroscopic properties there was elected double-layer textile and fabric. In the process of respiration between the human body and the respiratory mask there appears a condensate, moisture that you want to eliminate to feel comfortable. Therefore, the inner layer of the samples allows the moisture transport, and the external layer, filtering and absorbing (Fig. 1) [5,6,15].

Fig. 1. Manufactured samples of textile respiratory masks

One of the important properties of the filter material is resistance to physical and chemical effects of water, vapour, daylight, high temperature, acids, alkalis and other chemical reagents. Most textile fibres are characterized by high resistance to various physical and chemical influences. Certain types of fibres exhibit these properties in different ways [7]. For example, humidity has little effect on synthetic fibres – those of polyester (PE), polypropylene (PP), polyamide (PA), polyvinyl-chloride (PVC). When they are wet the stretching of all types of fibres, except synthetic ones, increases in some cases up to 25-30%. Strength under the influence of water grows only in natural cellulosic fibres – cotton, elementary fibres of flax, hemp. In other types of fibres, with the exception of some synthetic (man-made) fibres – viscose rayon, copper-ammonia, acetate, and protein fibres – the strength is reduced by 40-60%.

Textile fibres generally are not affected by water and vapour when their temperature is less than 100°. Under the influence of daylight and due to oxidative processes fibres gradually undergo the process of "aging", which is revealed in a decrease in strength and the degree of stretching, in the increase of rigidity and brittleness. It has been found that in the most destructive way daylight affects silk fibres, and the most resistant to this action are the fibres of wool and acrylic [15].

Most textile fibres satisfactorily withstand the temperature of about 120-150°, and when moisturized, even a higher temperature. However, synthetic fibres, such as PA, PP, PE, etc., are thermoplastic, that is, under a high temperature, they first deform and then melt. Therefore, products made of these fibres or when mixed with other fibres, should not be exposed to high temperatures.

Acids, alkali and other chemical reagents that are used in the processing and operation of textiles, affect textile fibres in different ways. Only materials made of synthetic fibres can satisfy most of the above specific requirements.

Most common are fibres of polyester, polypropylene, polyamide yarns. For the manufacture of samples, in the function of a hydrophilic raw material was used the yarn of the following composition: cotton 34%, linen 33%, viscose 33%. As a hydrophobic raw material was used polypropylene multifilament yarn. The combination of natural and synthetic materials produces different kinds of masks for different operational conditions.

The consumption of natural fabrics correlates with their surface density, and that of synthetic fabrics, with their weight. Reduction in consumption of textile materials is one of the main tasks of the textile industry. But the reduction of the quantity of materials should not reduce their quality considering their destination and conditions of use.

The characteristics of the properties of textile materials that determine the main functions of their destination also predetermine the area of their application.

The operational properties of textile materials depend on the mechanical properties of textile products that are determined by the reaction of the textile material to an external influence that cause deformation during stretching or compression, which leads to negative processes.

The surface density is one of the main technological parameters whose value determines both the physical, mechanical and consumer properties of textile materials. This characteristic of thickness as well as that of the consumption of textile materials and products are determined according to standard methods.

Methods for the determination of the surface density of textile materials are time-consuming due to the necessity to stop the production processes to obtain samples, which adversely affects both the quality of the product and the reliability of the results. Therefore, for operational control of the surface density of textile materials it is advisable to use non-destructive control methods [15].

The aim of this work is to foretell and control the quality of the materials for the manufacture of means of human protection from negative environmental influences. The purpose of the research is to improve the ultrasound method for determining the surface density of materials for making respiratory protection.

2. Materials and methods

As a result of our research and analysis of the influence of properties of textile materials on quality indexes of the corresponding products, there was developed a double-layered textile and were manufactured respiratory masks for protecting human respiratory organs from harmful substances. There was made an analysis of the range of protective masks for sports and domestic destination.

The tasks we set included the design of means of protecting human respiratory organs, modernization of the samples existing in the market by applying the developed weaves and new raw materials, as well as the study of the basic properties of the fabricated samples and the development of multifunctional textile materials, with layers of diametrically opposite properties.

In the process of designing textile materials, their operational properties are to be taken into account, namely, the initial data for manufacturing fabric and textile of a given structure: density, raw material composition, linear density of the yarns used, and the surface density. All these indicators determine the physical, mechanical and operational properties of textile materials.

When designing a new range of fabrics, we elaborated the most rational method of production, which causes the control of the materials while their physical and mechanical properties remain unchanged or are improved.

The origins of the theory of the design of the fabrics date back to the beginning of the XIX century, when there was established the dependence of the density of the fabrics on the ratio of linear densities of the yarn from which they are made and when there were elaborated the theories of design of fabrics that have been used in the practice up till now.

We developed the author's program "Interweaving" which greatly simplifies the process of creating a visual 2-and 3-dimensional fabric models with the given parameters (type of weaving, linear density of the warp and the weft, the colours of the pattern of the fabric).

The process of obtaining a three-dimensional model is divided into three parts. The first step is to select raw materials or colours for the future sample and the weaving refrain (Fig. 2). During the second phase we obtain a two-dimensional model with the ability to change the scale of the drawing. During the third stage we have a three-dimensional model that is displayed in the main window "3D model obtained pattern" and we can choose one of the two display modes.

When the parameters of the yarn and the pattern of the weave are changed, are these modifications are automatically shown in the second window – "The pattern obtained".

Figure 3 shows the result of the design of the fabric of plain weave. If necessary, it is possible to change the diameter of the threads and the rotation parameters of the sample.

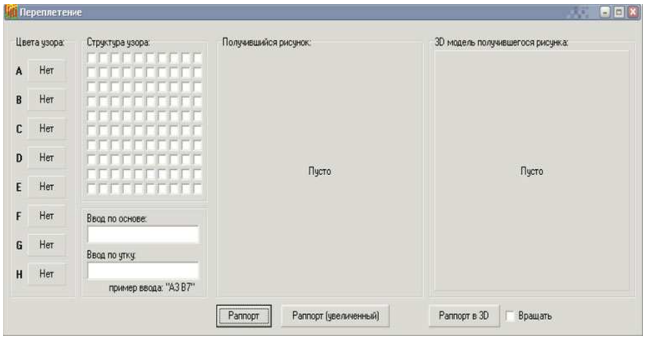

Fig. 2. Working window of the program "Interweaving": setting the colours of the pattern, the structure of the material and getting a picture of fabric and its 3D model

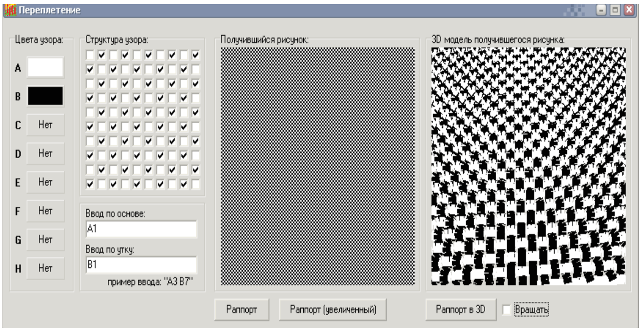

Fig. 3. Working window display of the fabric of plain weave using two types of yarn

The problem of structure and design of fabrics has not lost its relevance especially because due to the use of computer technology and systems of automatic design of textile materials, hence the need for systematization and the development of methodology for their design and control.

This method is original, authorial. Similar studies were not carried out by scientists.

We created an ultrasonic resonance thickness gauge, in which the introduction of new elements and connections improved the accuracy of measuring the thickness of materials and products controlled, without additional measurements of the propagation velocity of ultrasonic vibrations in them [15].

The ultrasonic resonance thickness gauge (Fig. 4) comprises a high-frequency generator, the output of which is connected to a high-frequency quadrature phase-splitter; balance modulators connected to the outputs of a phase-splitter and to the inputs of an adder; an amplifier of high-frequency oscillations; a dual element piezoelectric transducer that comprises a disc emitter and a ring receiver; a high-frequency amplifier connected to the output of the receiver; an amplitude and phase detectors connected with their inputs to the output of the high-frequency amplifier; low-frequency amplifiers and synchronous detectors joined consecutively and connected to the outputs of the amplitude and phase detectors respectively; an integrator connected with its input to the output of the synchronous detector and with its output, to the control input of the block of frequency tuning of the high-frequency generator 1; differential amplifier; a reference voltage source connected with one input of the differential amplifier, the other input being connected to the output of the synchronous detector; an integrator connected with its input to the output of the differential amplifier and with its output, to the control input of the block of adjustment of the low-frequency generator, to the output of which is connected the low-frequency quadrature phase-splitter, the outputs of which are connected to the inputs of a bipolar automatic switch; a multivibrator connected with its output to the control inputs of the synchronous detectors and the control input of the automatic switch, the outputs of which are connected to each other and to the control inputs of the balance modulators; a microprocessor-based frequency counter, the inputs of which are connected to the output of the high-frequency generator and the output of the low-frequency generator.

The textile material is fed in the form of a flat layer of thickness h, whose surface density can be monitored when flat ultrasonic waves pass through it during its normal fall, taking into consideration the multiple reflections of the waves at both boundaries [15].

Complex transmission coefficient of W. Let us denote the acoustic resistance of the medium from which the ultrasonic wave falls as z_1, the material that is controlled, as z_2, and the medium where the ultrasonic wave gets in, as z_3, ($z=pc$ where p and c are the density and the speed of propagation in the ultrasonic waves respectively). Let the amplitude of the wave that falls on the controllable material be equal to P_0, and that of the one that passed through it, P_n. Then the ultrasonic wave that has passed through the layer of the material monitored may be represented as the superposition of the following waves: the wave that passed through the boundary between media 1 and 2, the layer and the boundary between media 2 and 3; the wave that passed the boundary between media 1 and 2, the layer, reflected from the boundary of media 2 and 3, passed the layer, reflected from the boundary of media 2 and 1, passed the layer and the boundary between media 2 and 3; the wave that passed the boundary between media 1 and 2, the layer, reflected from the boundary of media 2 and 3, passed the layer, reflected from the boundary of media 2 and 1, passed the layer, reflected from the boundary of media 2 and 3, passed the layer, reflected from the boundary of media 2 and 1, passed the layer and the boundary of media 2 and 3, etc.

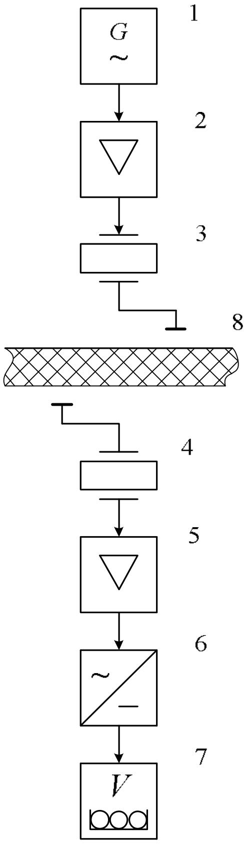

Fig. 4. Functional diagram of the ultrasonic device to control the surface density of textile materials: 1 – generator; 2,5 – amplifier; 3 – ultrasonic transmitter; 4 – ultrasonic receiver; 6 – converter; 7 –voltmeter; 8 – textile material

The scheme (Fig. 4) works as follows. A signal with a sinusoidal shape and an ultrasonic frequency of 18-22 kHz from the generator 1 enters the amplifier 2, after which it stimulates ultrasonic oscillations in the actuator 3. The actuator is used for the piezoelectric or magnetostrictive type, depending on the required power. After passage of the layer of investigated textile material 8, the signal is converted from the ultrasonic to the electrical form in the piezoelectric converter 4. Then, the signal amplifies in the amplifier circuit 5 and enters the detector 6, which allocates the amplitude value of the sinusoid in the form of a constant voltage. The constant voltage is displayed on the digital voltmeter display 7. The value of the constant voltage at the output of the meter's path depends on the coefficient of attenuation of the ultrasound in the material. The coefficient of attenuation depends on the density of the material. Thus, we use a known voltage dependence on the output of the device from the density. In this case, the scale of the output device (voltmeter) can be graded in accordance with the density.

The complex amplitudes of these waves, taking into account the phase multipliers, may be represented as follows:

$$P_1 = P_0 W_{12} W_{23} e^{jk_2 h},$$
$$P_2 = P_0 W_{12} W_{23} V_{23} V_{21} e^{3jk_2 h}, \qquad (1)$$
$$P_3 = P_0 W_{12} W_{23} V_{23} V_{21} V_{23} V_{21} e^{5jk_2 h},$$

where W and V are the corresponding coefficients of transmission and reflection of waves at the boundaries of the corresponding media (in this case, the first indicator denotes the medium from which the wave falls and the second indicator, the medium into which it passes or from which it is reflected); k is the wave number of the material of the layer.

$$P_n = \sum_{i=1}^{n} P_i = P_0 W_{12} W_{23} e^{jk_2 h} + P_0 W_{12} W_{23} V_{23} V_{21} e^{3jk_2 h} + \\ + P_0 W_{12} W_{23} V_{23} V_{21} V_{23} V_{21} e^{5jk_2 h} + \ldots \qquad (2)$$

Transmission coefficient we define as:

$$W = P_n / P_0 = W_{12} W_{23} e^{jk_2 h} \sum_{n=0}^{\infty} (V_{23} V_{21} e^{jk_2 h})^n \qquad (3)$$

The expression (3) is the sum of an infinite geometric progression that is decreasing (due to inequality). The sum of such a progression we define as:

$$W = \frac{W_{12} W_{23} e^{jkh}}{1 - V_{23} V_{21} e^{2jk_2 h}} \qquad (4)$$

Using the known correlations for coefficients of transmission and reflection:

$$W = \frac{4 z_1 z_2}{(z_1 + z_2)(z_2 + z_3) e^{-jk_2 h} - (z_2 - z_3)(z_2 - z_1) e^{jk_2 h}} \qquad (5)$$

If the medium on both sides of the layer is the same (5) and if we neglect the imaginary part of the acoustic resistance of the material of the layer, we shall obtain:

$$W = \frac{1 - \alpha h}{\sqrt{\left(1 + \frac{\left(\frac{z_2}{z_1} - 1\right)^2}{2\frac{z_2}{z_1}} \alpha h\right)^2 + \left(\frac{\left(\frac{z_2}{z_1}\right)^2 - 1}{2\frac{z_2}{z_1}}\right)^2 (1 - 2\alpha h)^2 \sin^2 \frac{2\pi h}{\lambda_2}}} \qquad (6)$$

where α is the attenuation coefficient in the material of the layer; λ_2 – is the length of the ultrasonic wave in the layer of the material.

If we neglect attenuation in the material of the layer that gives an error of less than 2 %, the expression (6) can be represented as follows:

$$W = \frac{1}{\sqrt{1+\left(\frac{(z_2/z_1)^2-1}{2z_2/z_1}\right)^2 \sin^2\frac{2\pi h}{\lambda_2}}} \quad (7)$$

When the air medium is used $z_2/z_1 >> 1$

In addition, by an appropriate choice of the frequency of ultrasonic oscillations it is possible to ensure the fulfilment of the condition $2\pi h/\lambda_2 << 1$. Then the expression (6, 7) can be represented as:

$$W = \frac{z_1}{\pi fd} = \frac{k_1}{d} \quad (8)$$

where – d is the surface density of the textile material; k_1 – is the coefficient of proportionality.

Figure 4 presents a functional block diagram of the ultrasonic device to control the surface density of textile materials.

The device comprises a generator 1, an amplifier 2, an emitter and a receiver of ultrasonic oscillations 3 and 4 respectively, an amplifier 5, an amplitude detector 6 and a digital voltmeter 7. The position 8 is the material whose surface density is being monitored.

The device operates as follows. Electrical oscillations from the output of the generator 1are amplified by the amplifier 2 and converted into ultrasound oscillations with the help of the emitter 3. Ultrasonic oscillations pass through air medium, the material 8 whose surface density is controlled, and are converted into electric oscillations with the help of the ultrasonic receiver 4. After that these ultrasonic oscillations are amplified by the amplifier 5 and get to the input of the amplitude detector 6, the output voltage of which is $U = k_2W = k/d$, where $k = k_1k_2$ is the proportionality coefficient, inversely proportional to the surface density d.

Since the reference signal of the differential amplifier is a constant value, the phase shifts of the reflected oscillations also stabilize. The changes of the velocity of propagation of oscillations in the material are compensated for by the change of the low modulating frequency. A measurement of the ratio of values of low and high frequencies in a microprocessor frequency gauge allows to get the result in the digital form, which is proportional to the thickness of the monitored material or product, irrespective of the variations in the speed of propagation of ultrasonic oscillations in it, which allows to increase the accuracy of thickness measurements of the controlled materials and products without additional measurements of the propagation velocity of these oscillations [15]. Due to the automatic adjustment of the frequency of the low-frequency modulating signal the phase shift of the ultrasonic oscillations that are reflected from the tested material stabilizes. The deviations of the phase shift through a change in the velocity of propagation of ultrasonic oscillations are compensated for by the corresponding changes of the probe oscillations of the upper and lower lateral frequencies in relation to the resonance frequency.

The ratio of stable values of low and high frequencies is proportional to the thickness of the controlled material or product and is not dependent on changes in the velocity of propagation of ultrasonic oscillations in the material, and consequently, on the values of physical and mechanical properties of these materials.

The above device was patented and used for the given research. The scheme is provided in Figure 5 [15].

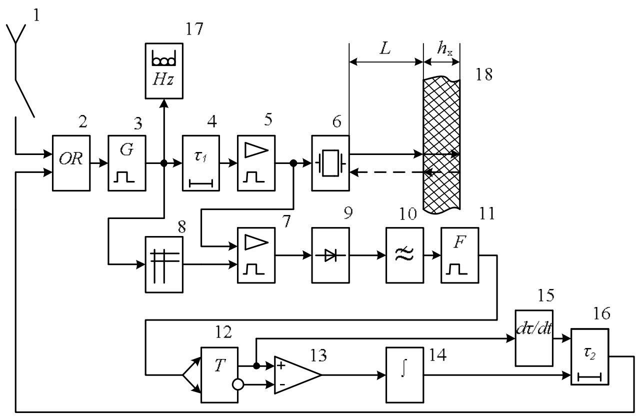

Fig. 5. Ultrasonic contactless thickness meter: 1 – external input; 2 – driver; 3 – pulse generator; 4, 16 – delay block; 5, 7 – pulse amplifier; 6 – ultrasonic transmitter/receiver; 8 – amplitude limiter; 9 – detector; 10 – filter; 11 – frequency detector; 12 – phase splitter; 13 – amplifier; 14– integrator; 15 – differentiator; 17 –voltmeter, 18–textile material

Let's take a look at the principle of the ultrasonic imaging device (Fig. 5). Key 1 allows you to translate the scheme into an irrelevant generation mode, which is important when you have a generator of rectilinear impulses. When a key 1 is set to “open” the generator 3 sends a signal to the input of the logical element OR 2, which is the main signal of the generator, which has a delay in accordance with a series of pulse generators. The delay value affects the amplitude of the voltage measured by the digital voltmeter 17. The delay time is directly proportional to the length of the acoustic path, which forms the thickness of the material h_x and the air gap L. Thus, on the voltmeter display, the voltage is proportional to the thickness the material.

Transformation and signal processing have several stages. After the delay line 4 pulses from the output of the generator are fed to an amplifier of power 5, and then converted into an ultrasonic transducer 6 on ultrasonic waves. After reflection from the back surface of the test material 18, the weakened ultrasonic signal is transformed into a piezoelectric device 6 again into an electric form. For the time separation of the series of exciting pulses and the reflected signal, the time delay lines 4 and 16 are assigned. The inputs of the amplifier 7 are received: the signal is reflected from the converter 6 and the signal of the generator, which is limited by the level on the element 8. The difference between these signals is increased. After the passage of the detector 9, the filter 10 and the frequency detector 11, a measuring pulse signal is formed which duration will be proportional to the thickness of the material 18. For the final formation of the pulse are intended: the phase separator 12, the amplifier 13, the integrator 14, the differentiator 15. After the delay on the element 16, the measuring pulse enters the permit input of the generator 3.

With the help of the ultrasonic thickness meter, we investigated the influence of technological factors and constructive parameters of the equipment on the change in the surface density of textile materials and on their operational properties, namely, the mechanical properties (deformation of the product).

The studies were conducted at different textile enterprises of Ukraine for textile products (fabrics and textiles) made of cotton, mixed yarn (a mixture of cotton, linen, nitronfibres), and basalt yarn.

We analysed fabrics made from different raw materials and weaves (linen, satin 5/3, twill 1/3). We investigated different fabrics: calico (art. 131) with a nominal surface density of 144 g/m^2, unbleached calico (art.142) with a nominal surface density of 226 g/m^2, "Kashtan (Chestnut)" (art. 6B0031) with a nominal surface density of 404 g/m^2.

The standard thickness measurement method is based on gluing a knit sample to a piezoelectric transducer. The time between any maximum sinusoid of one of the reflected pulses and the corresponding maximum of any other pulse depends on the delay time in the sample itself when the wave propagates from the radiator to the reflecting surface and back, from the number of such cycles of reflection, from the phase shift upon reflection and from the total number of periods. At a known speed of sound, the thickness of the fabric sample is determined.

For each article of textiles, we studied the error of the measurement of surface density using the standard method, the ultrasonic method and its nominal value. It should be noted that these errors occur when the entire range of fabrics is controlled without readjustment of the device to control the surface density of a specific fabric. When you run this operation for a specific fabric the error does not exceed 2.5%.

When studying the changes in the indicators of the surface density of textile materials in the production process we recorded the changes in the deformation characteristics of a given material, namely, the value of the breaking load, which allowed to make a conclusion as to direct correlation between these values. Thus, the operational properties of textile materials depend on the changes in their surface density in the process of production, which in their turn depend on the constructive parameters of the equipment.

3. Results and discussion

In order to ensure a uniformity of physical and mechanical properties of the textile material in the process of weaving and textile production it is necessary to control the indicators of the surface density of the resulting product to ensure identical operational characteristics, which is possible due to the use of the ultrasonic method of the control of the surface density.

Thus, the conducted studies allowed to determine the advantages of using the ultrasonic amplitude method for controlling the surface texture density of a textile materials. The expediency of using the method for controlling the surface density of textile materials as an express method has been proved, which significantly reduces the time of obtaining the result of measurement. The method of measurement has been tested on various textile enterprises of Ukraine. The following fabrics samples of different raw materials and interweaving were selected for research – linen, satin 5/3, twill 1/3. Investigated fabrics: calico (art. 131) with a nominal surface density of 144 g/m^2, unbleached calico (art.142) with a nominal surface density of 226 g/m^2, "Kashtan (Chestnut)" (art. 6B0031) with a nominal surface density of 404 g/m^2. The accuracy of measuring the surface density of each sample of tissue was determined according to the standard method and developed by the ultrasonic amplitude method. A comparative analysis of the measurement results allowed to assert that the measurement error of the surface texture density of textile materials by the ultrasonic amplitude method decreased by 10% and did not exceed 2.5%.

4. Conclusions

1. The problems of structure and design of fabrics have not lost their relevance, especially due to the use of computer technologies and systems of automatic design of textile materials, therefore, the invention of new methods of designing textile materials allows to increase their assortment There is a need to systematize and develop a methodology of fabrics design and control.
2. In the course of the research we justified the possibility of using the ultrasonic amplitude method to control the surface density of the textile material. The given experimental studies of the ultrasonic non-contact device showed the feasibility of its use for online process control of the surface density of textile materials. Further theoretical and experimental studies should be aimed at expanding the control range of this indicator and at eliminating the influence of destabilizing factors (temperature and humidity fluctuations) on the result of the control.
3. Further theoretical and experimental studies are aimed at expanding the range of control of the surface density of fabrics and knitwear, excluding the influence of destabilizing factors on the result of control, the use of textile materials with controllable properties for the production of individual means for protecting people from the negative effects of the environment, namely dust. The selection of textile materials is very important for the implementation of scientific research in production; therefore, the purpose of further work is the selection, definition and control of the qualitative indices of the material for the manufacture of individual means for protection, the introduction of methodology and the manufacture of hygiene products on an industrial scale. Also, studies on the determination and quality control of textile materials for hygiene products after application of different bactericidal solutions will be continued.

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