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Contactless ultrasonic method for determining knitted fabrics tension

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ABSTRACT

Purpose: of this paper is to provide operational tension control of fabric on knitting equipment using ultrasonic contactless transducers to improve the quality characteristics of the finished product.

Design/methodology/approach: It has been established that the amplitude of ultrasonic waves passing through different zones of the textile material can be used to determine the tension of the knitted fabric over the entire width of its fabric.

Findings: The possibility and expediency of determining the fabric tension on knitting equipment by using the ultrasonic contactless method has been shown. The tension of the knitted fabric in its manufacture is the main technological parameter, the value of which determines the physical, mechanical and consumer properties of the finished fabric, especially basis weight. The use of operational technological control of the tension of knitted fabrics directly during their production will improve the quality of finished products, and, accordingly, the reliability of use in personal protective equipment, in particular in body armour. It has been proposed to determine the tension of knitted fabrics in their production on knitting equipment by changing the amplitude of ultrasonic waves passing through the material under the action of tension, which also changes during the movement of the process equipment. The proposed contactless method is quite promising, since it has a number of significant advantages over the existing contact methods. In the course of the research, experimental measurements of the amplitude of ultrasonic waves have been carried out. These waves passed through samples of fabric of various materials while stretching. The samples of knitted fabrics were irradiated with an ultrasonic pulse signal with a wave frequency of 40 kHz. The samples of knitted fabrics from 58x2 Tex Kevlar threads and high molecular weight 44x3 Tex polyethylene yarns with double weave 1x1 elastic have been taken as a basis for the research.

Research limitations/implications: For textile fabrics, the structure of which does not allow stretching through pores under the action of tension, it is necessary to additionally adjust the contactless sensors in frequency and capacity depending on the corresponding sample.

Practical implications: The values of the measured amplitudes of ultrasonic vibrations that have passed the controlled material have been obtained. These values were compared with the amplitude of the waves passing through the fabric sample when the initial tension was applied to it. After that, the total current value of the tension of each sample of the knitted fabric in its three zones was determined. The distribution of the total tension in different zones of the sample material was also determined.

Originality/value: The dependences of the amplitude of ultrasonic waves, transmitted through the textile material in its different zones, on the value of the total tension, and on the value of the distribution of the tension of the fabric over its entire width were obtained. The deviations δ_P of the tension display between the determination of this parameter by the standard and ultrasonic methods are shown. The deviations δ_U between the amplitudes of waves passing through different zones of the controlled fabric are also determined.

Keywords: Tension of textile fabric, Amplitude of ultrasonic waves, Contactless control, Through pores of the material, Interfibre porosity

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PROPERTIES

1. Introduction

Nowadays, a rather urgent task is the use of heavy-duty materials for the development of new personal protective equipment, as well as their control in the process of manufacturing finished fabrics to maintain the proper quality of products. For manufacturing knitted fabrics of increased strength in work [1], it is proposed to use double needle bar circular knitting machines of 10-16 classes with an interlock arrangement of needles, which will ensure the processing of heavy-duty yarns and obtain a two-layer knitted fabric with the required quality indicators. It is known that in the world analogues of ballistic textile materials, two types of raw materials are mainly used to give them functional properties: Kevlar threads from DuPont (USA) and high molecular weight polyethylene threads of the Dyneem trademark from DSM (Netherlands). Less common is the use of their counterparts (Twaron, Technora, etc.). Dyneem fibres are characterized by low weight, resistance to almost all types of chemicals and ultraviolet rays, lack of extensibility, and at the same time they do not lose their strength during operation. The advantage of Kevlar is the retention of its strength at low and high temperatures, incombustibility and tensile strength. In turn, Dyneema® ultra-high molecular weight fibres are made from polyethylene, which allows to create a unique synthetic material that exceeds the strength of steel by 15-20 times. The use of ballistic knitted fabrics containing these threads in their structure will increase the protection class of the body armour and significantly reduce the weight, provided that the thickness of the protective plates made of armoured steel is reduced and a knitted substrate (filler) is introduced to protect against splinters and ricochet.

For personal protective products, the authors of [1] recommend the use of a two-layer fabric with a press connection of the layers of the main threads. It is the two-layer weave that allows to increase the elasticity of the fabric using an inextensible thread, as well as combine different types of raw materials in one fabric, provided they are clearly differentiated in layers. High molecular weight polyethylene thread of the Dyneema® trade mark with a linear density of 44 tex has been recommended to use to form the front layer of the fabric. The main problems in manufacturing this fabric are the selection of the depth of adjustment to create a loop in order to balance the formed layers of two-layer knitwear; the establishment of the required size of the shedder between the needle bars; the provision of a pulling force for the removal of the two-layer fabric into the gap between the lines. It is for the possibility of realizing the operative adjustment of the pulling force of the knitted fabric, it is important to control its tension in various zones during the manufacturing process, which is an important task to ensure the high quality of the finished product.

At present, the analysis of ensuring continuous monitoring of both the tension of the threads [2-4] on various textile machines and the tension of textile fabrics [5-14] makes it possible to control the uniform value of the technological parameter of the fabric on knitting machines, on which the uniformity of the structure, porosity and maintaining the same areal density at every point of the material depend. To ensure operational control of the fabric tension on textile machines, it is advisable to use contactless technologies.

Among the contactless transducers that are safe for humans and fairly easy to set up and operate there are ultrasonic ones [15,16]. If we compare common optical sensors [17] with ultrasonic ones, then their sensitivity to textile material is limited, which is associated with the wavelength that will be reflected from the smallest fibre of the material and will not pass through the thickness of its layer. Also, the display of optical sensors can be affected by the dustiness of the room where they are installed. Other existing sensors used to determine the tension of textile materials are contact [18,19]. This makes their application for operational control a rather difficult task. Based on the above, we can say that contactless ultrasonic systems for determining the tension of textile fabrics are promising for obtaining information about the value of the parameter at each point of the fabric during its production. This will, in turn, ensure the quality characteristics of the fabrics produced at a sufficiently high level and improve technological equipment for various processes in the textile industry.

One of the tasks for contactless control of the tension of a textile fabric is to eliminate the influence of the structure of the fabric itself on the change in the size of its pores in the process of stretching textile fibres. By changing the interfibre distances and the size of the through pores in the structure of the material, it is possible to determine the magnitude of its tension. The porosity of a textile material per unit of its area, or its change at a certain point in time, affects the amplitude of ultrasonic waves [20] that pass through the controlled fibres of the material. Also, the size of the through pores affects the amplitude of the wave passing through them. The more the pores of the fabric and the interfibre distance increase or decrease when the fibres of the knitted fabric are stretched, the amplitude of the probing wave will change accordingly. A variant is possible when the through pores can expand, and the interfibre distances will decrease. In this case, their complex effect will be displayed on the amplitude of waves that have passed through the structure of the knitted fabric with a certain tension. With a significantly greater effect of tension on the change in the interfibre distances due to the change in the size of the pores themselves, or when the distances between the fibres of the material and the pores themselves equally decrease when the fabric is tensioned, it is possible to better determine the unknown parameter from the amplitude of the probing waves.

In the course of the research, experimental measurements of the amplitude of ultrasonic waves were carried out, which passed samples of fabrics of different materials when they were stretched. The samples of knitted fabrics were irradiated with an ultrasonic pulse signal with a wave frequency of 40 kHz. The samples of fabrics with Kevlar threads and polyethylene yarn were taken as a basis for the research.

2. Theory

Let us consider the passage of a plane ultrasonic wave through a controlled knitted fabric of a double weave 1x1 elastic at its normal incidence from the medium (air) with acoustic resistance ($Z_1 = \rho_1 c_1$, where $\rho_1 c_1$ is the bulk density of the medium and the velocity of propagation of the ultrasonic wave in it). The knitted fabric of the 1x1 elastic weave consists of front and back loops that form two layers. The first layer with thickness h_1 has acoustic resistance Z_2. The second layer of knitted structure with thickness h_2 has acoustic resistance Z_3 and rests on a medium with acoustic resistance Z_4.

If there is air on both sides of the knitted fabric, then $Z_4 = Z_1$.

The ultrasonic pulse signal in the form of a function of the pressure change in the wave $P_{1m}(t')$, which passed through the controlled knitted fabric of the double weave, considering the wave propagation time t', can be determined as follows:

$$P_{1m}(t') = \frac{1}{2\pi}\int_{-\infty}^{\infty} W(\omega)\, S(\omega) \cdot e^{j\omega t'} d\omega \ , \tag{1}$$

where:
$S(\omega)$ is spectral density of the incident ultrasonic signal;
$W(\omega)$ is complex transmission coefficient of ultrasonic waves of the knitted fabric considering the attenuation depending on frequency ω.

The complex coefficient of ultrasonic waves transmission through the knitted fabric at $Z_2 > Z_1$, $Z_3 > Z_1$, $Z_2 > Z_4$, $Z_3 > Z_4$ can be represented as follows:

$$W = \frac{2Z_1}{Z_1+Z_2} \cdot \frac{2Z_2}{Z_2+Z_3} \cdot \frac{2Z_3}{Z_3+Z_4} \times \sum_{N=0}^{\infty} \left(1 - \left(1 - \frac{Z_2-Z_1}{Z_2+Z_1} \cdot \frac{Z_3-Z_4}{Z_3+Z_4}\right)\left(1 + \frac{Z_2-Z_3}{Z_2+Z_3}\right)\left(1 + \frac{Z_3-Z_2}{Z_3+Z_2}\right)\right)^N \times e^{-(2N+1)\left(-j\frac{\omega b}{c_{23}}+\alpha_{3.}\right)\cdot(h_1+h_2)\cdot \cos\nu}, \tag{2}$$

where:
N is the number of re-reflections of waves equal to 0, 1, 2, 3, …, ∞;
ν is the angle between the direction of ultrasonic waves propagation that pass through the pores and surface of the knitted fabric;
$b = \omega/\omega_0$ is the coefficient of the ratio of the carrier circular frequency and the circular pulse signal filling frequency;
α_3 is the general coefficient of extinction of ultrasonic waves in the material;
$c_{23} = (c_2 + c_3)/2$ is the average velocity of propagation of an ultrasonic wave in the material.

The module of the complex transmission coefficient itself can also be represented as:

$$|W| = U_1/U_0, \tag{3}$$

where:
U_0 is the voltage that is formed on the amplitude detector, proportional to the amplitude of the ultrasonic waves incident on the knitted fabric;

U_1 is the voltage generated on the amplitude detector, proportional to the amplitude of the ultrasonic transmitted through the knitted fabric.

If we consider the contactless determination of the change in the tension of the textile fabric during its transverse probing, then the average change in this parameter in a certain area of the material area can be determined from the change in the size of interfibre pores. This change in porosity is caused by a change in the diameters of the threads in the structure of the textile when it is tensed. In turn, the change in the dimensions of the diameters of the threads can be determined by changing the amplitude of the waves passing through the controlled fabric, such a dependence can be shown as follows:

$$P^* = P \cdot \left(\frac{|W|_k}{|W|_{k+1}}\right)^3 = P \cdot \left(\frac{U_k}{U_{k+1}}\right)^3, \tag{4}$$

where:

P, P^* are initial and current tensions of the fabric sample, associated with a certain area of the controlled knitted fabric;

k – index, which determines the value of tension; $k = 0$ – without tension (zero tension); $k = 1$ – the first value of tension; $k = 2$ – the second value of tension (increased relative to the first value of tension);

$|W|_k$, $|W|_{k+1}$ are the modules of the wave amplitudes passing the controlled knitted fabric at initial and current tensions;

U_k is the voltage from the detector of the measuring channel, proportional to the amplitude of the ultrasonic waves passing through the sample fabric in a certain zone before changing the first current tension value, as indicated by the k index;

U_{k+1} is the voltage from the detector of the measuring channel, proportional to the amplitude of the ultrasonic waves passing through the sample fabric in a certain zone after changing the current tension value, as indicated by the $k + 1$ index.

Using the amplitude of ultrasonic waves, it is possible to determine the change in the tension of the textile fabric in certain zones when the material is sounded.

3. Research results

All measurements of the amplitude of ultrasonic vibrations were made in comparison with the amplitude of the waves that passed through the sample of the fabric when the initial tension was applied to it. After that, the current value of tension was determined for each sample of knitted fabric in its three zones (see Fig. 1). At this moment, the tension distribution was determined in the second zone of the stitch rows (designation 2 for this zone), as well as in the extreme first and third zones of the material (designations 1 and 3 for the extreme zones), where the boundaries of the more deformed stitch rows of the sample are located.

Two weights were suspended from the samples at the edges $P_1{}^*, P_3{}^*$, which caused local tensions in zone 1, 3 the most, and in zone 2 of the material partially. The approximate current total value of the sample tension $P^* \approx P_1{}^* + P_3{}^*$ and its components $P_1{}^*, P_3{}^*$ were determined using the amplitude dependences of the waves passing through zones 1 and 3 on the fabric, as follows:

$$P_1{}^* = P_1 \cdot \left(\frac{U_{1k}}{U_{1k+1}}\right)^3, \quad P_3{}^* = P_3 \cdot \left(\frac{U_{3k}}{U_{3k+1}}\right)^3, \tag{5}$$

where:

P_1, $P_1{}^*$ are initial and current tensions of the fabric sample, which are associated with the first and partially with the second zones of the knitted fabric sample;

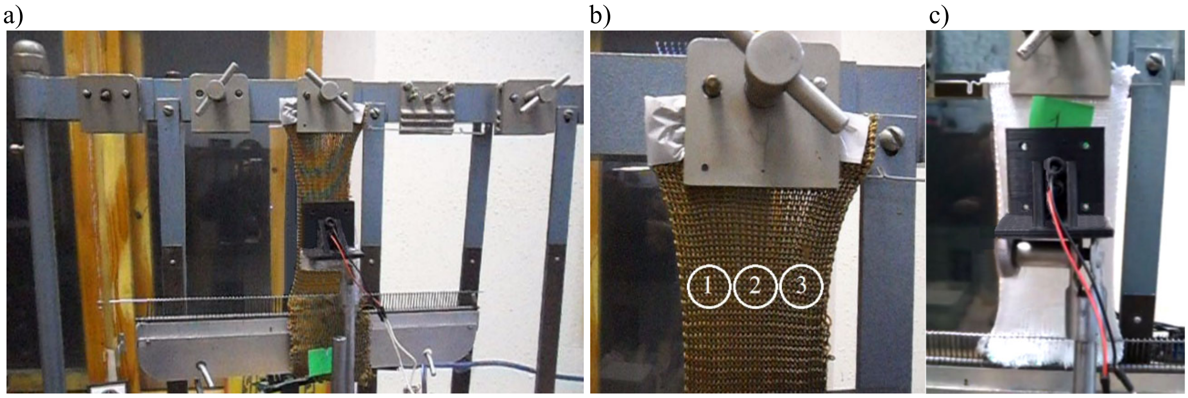

a)
b)
c)

Fig. 1. Ultrasonic determination of the tension of prototypes of knitted fabrics of Kevlar (a), the zones 1, 2, 3 of the sound (b) and high molecular weight polyethylene threads (c)

P_3, P_3^* are initial and current tensions of the fabric sample, which are associated with the third and partially with the second zones of the knitted fabric sample;
n is number a of the zone;
U_{nk} is the voltage proportional to the amplitude of the ultrasonic waves passing through the appropriate sample of the knitted fabric at the appropriate value of tension.

A comparison was made of the values of the amplitudes of the waves that passed through the material to be inspected at its different tensions, determined using the standard contact method, and at the tension determined using the contactless ultrasonic method. The total sample tension P^* was determined using the dependence (5), which is shown in Figure 2a. If we imagine the magnitude of the deviation δ_P of the tension displays between the determination of this parameter by standard and ultrasonic methods, then it can be presented as follows:

$$\delta_P = \left(\frac{P_1^* + P_3^* - P_{m1} - P_{m3}}{P_{m1} + P_{m3}}\right) \cdot 100\%, \tag{6}$$

where P_{m1}, P_{m3} are tensions of the fabric associated with the first, third and second zones of the knitted fabric sample, determined by the standard method due to the mass of two suspended weights towards the material.

The dependences of the deviations δ_P from the growth of total tension $P^*$for samples of various knitted fabrics are shown in Figure 2b.

When the current tensions in zones 1 and 3 are equal $P_1^* = P_3^*$, considering the amplitude of ultrasonic waves passing through the middle zone 2 of the sample, expression (5) can also be shown as:

$$P_1^* = P_3^* = \frac{(P_1 + P_3)}{2} \cdot \left(\frac{U_{2k}}{U_{2k+1}}\right)^3, \tag{7}$$

It should be noted that the dependence (7) in the calculation will give a less accurate result (see Fig. 3a), since the tension from zones 1 and 3 to zone 2 of the sample fabric is distributed unevenly through the loop rows, which can lead to significant deviations of the controlled parameter. Based on the above, we can say that a lower tension in zone 2 of the sample less deforms the threads and pores of the material. Therefore, the amplitude of the wave passing through this zone will often be larger for different materials. If we record the amplitude deviation δ_U of the waves passing through zone 2 and proportional to the voltage U_{2k}, in comparison with the waves passing through zones 1 and 3 of the sample fabric and proportional to the voltages U_{1k}, U_{3k}, at $P_1^* = P_3^*$, then such an expression can be shown as:

$$\delta_U = \left(\frac{U_{2k} - U_{1k}}{U_{1k}}\right) \cdot 100\% = \left(\frac{U_{2k} - U_{3k}}{U_{3k}}\right) \cdot 100\%. \tag{8}$$

The dependences of the deviations δ_U from the growth of the total samples tension P^* of various knitted fabrics are shown in Figure 3b. Table 1 presents the characteristics of

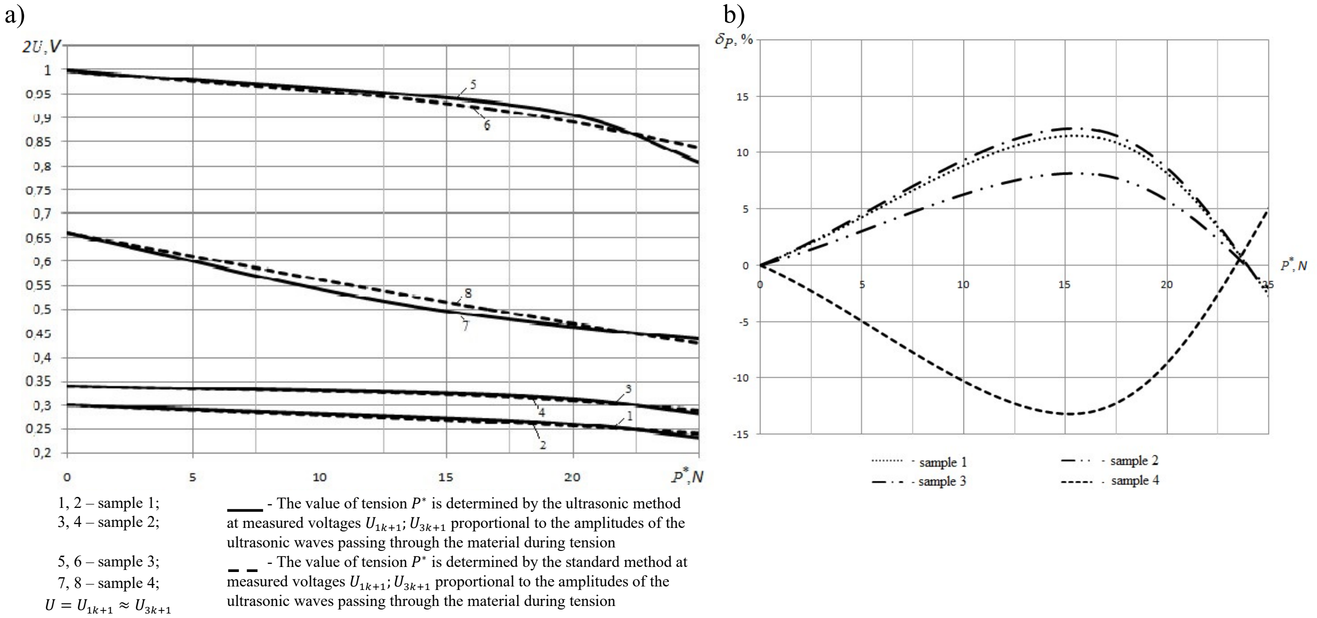
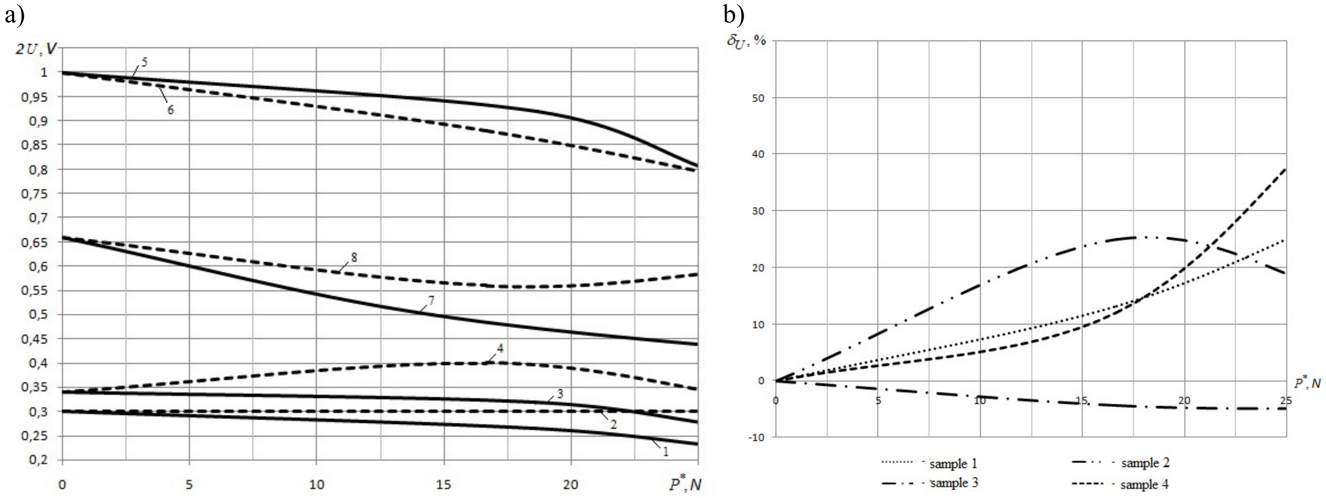


Fig. 2. Dependence of voltage $2U$ and the relative deviation from the tension P^*in knitted fabric samples when they sound in zones 1 and 3 of the material: a) dependence of voltage $2U$ from the tension $P^*$of samples of knitted fabrics; b) dependence of the relative deviation $\delta_P$from the tension $P^*$of samples of knitted fabrics



1, 2 – sample 1;
3, 4 – sample 2;
5, 6 – sample 3;
7, 8 – sample 4;
$U = U_{2k+1}$

—— - The value of tension P^* is determined by the ultrasonic method at measured voltages $U = U_{2k+1}$ proportional to the amplitudes of the ultrasonic waves passing through the material during tension

– – - The value of tension P^* is determined by the standard method at measured voltages $U = U_{2k+1}$ proportional to the amplitudes of the ultrasonic waves passing through the material during tension

Fig. 3. Dependence of voltage $2U$ and the relative deviation δ_U from the tension P^* in knitted fabric samples when they sound in zones 1 and 3 of the material: a) dependence of voltage $2U$ from the tension P^* in the samples of knitted fabrics, b) dependence of the relative deviation δ_U from the tension P^* in the samples of knitted fabrics

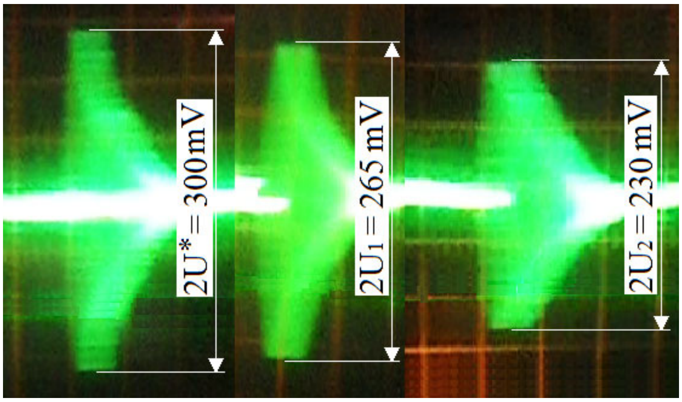
Table 1.
Characteristics of prototypes of knitted fabrics

Sample number	Type and linear density of the thread	Thread length in loop, mm	Basis weight, g/m^2
1	paraaramid thread 58x2 Tex	12.85±1.0	630.0±5.0
2	paraaramid thread 58x2 Tex	13.8±1.0	610.0±5.0
3	paraaramid thread 58x2 Tex	14.76±1.0	590.0±5.0
4	high molecular weight polyethylene thread 44x3 Tex	13.4±1.0	572.0±5.0

the prototypes of knitted fabrics. Oscillograms of ultrasonic waves, which passed through the prototypes of knitted fabrics when stretching the material and at rest without tension in different zones of the loop rows (zones 1, 2 and 3), characterize their interaction with the material. Oscillograms of waves that interacted with three prototypes of knitted webs of 1x1 elastic weaves from paraaramid Kevlar threads of linear density 58x2 Tex, and waves passing through a prototype of knitted weave 1x1 elastic from high molecular weight polyethylene threads 44x3 Tex. All prototypes of knitted fabrics are made on a flat knitting machine of 8th class with the same number of working needles (64 needles) and the same pulling force of the fabric 28.4H. Studying the passage of ultrasonic waves through the test specimens of knitted fabrics, the amount of tension corresponded to the minimum (16.8 N) and maximum (28.4 N) level of tension of the fabric, which ensures the normal course of the looping process. The tension force was applied to the test piece of knitwear evenly to each loop column as in the process of its production on knitting equipment. In order to study the sensitivity of ultrasonic waves to the density of knitting, test specimens 1-3 were made at three levels of cooling depth (2.5 mm; 3 mm; 3.5 mm), which caused a change in thread length in the loop and, accordingly, the through porosity. Samples 1 and 4 do not differ in the parameters of knitting (the number of needles in the work – 64, the depth of cooling – 2.5 mm, the pulling force of the fabric 28.4 N). The difference lies in the raw material composition of the prototypes, which allows to identify the influence of mechanical characteristics of high-strength yarns on the change in tension of the fabric in some areas. The results of experimental studies are shown in Tables 2-5.

Table 2.
The results of experimental studies (sample 1)

Voltages proportional to the amplitudes of the ultrasonic waves passing zone 2 of the test sample 1		
$2U^* = 2U_{20} = 300$ mV	$2U_1 = 2U_{21} = 300$ mV	$2U_2 = 2U_{22} = 300$ mV
-	$\delta_U = 13.1$ %	$\delta_U = 30.43$ %
Tension determination by the standard method		
P* = 0	P* = 16.8 N	P* = 28.4 N
Oscillograms of voltage proportional to ultrasonic waves passing through zone 3 of the test sample 1		



$2U^* = 2U_{30} = 300$ mV	$2U_1 = 2U_{31} = 265$ mV	$2U_2 = 2U_{32} = 230$ mV
Determination of tension by the standard method		
$P^* = 0$	$P^* = 16.8$ N	$P^* = 28.4$ N
Determination of tension by contactless ultrasonic method		
-	$P^* = 18.57$ N	$P^* = 25.51$ N
-	$\delta_P = 11.32\%$	$\delta_P = -10.17\%$

In order to contactless determination of the distributed tension in zones 1, 2 and 3 of the fabric sample, it is necessary to compare the amplitude of ultrasonic waves passing through these zones of the material. Different pore sizes and interfibre distances in zones 1, 2, 3 of the sample make it possible to compare different magnitudes of the amplitudes of ultrasonic waves passing through them. This characterizes the different distribution of tension over the entire width of the fabric. Figure 4a shows how the value of voltages changes, which are proportional to the amplitudes of ultrasonic waves passing through the material in zones 1, 2 and 3 of the fourth sample shown in Figure 1. The distribution of sample tension over the knitted fabric for each zone of the material using the amplitudes of the probing ultrasonic waves at $P_1^* = P_3^*$ or $U_{1k+1} = U_{3k+1}$ can be calculated then as follows:

$$P_{1z}^* = P_{3z}^* = \frac{(P_1^*+P_3^*)}{2N_z}\cdot\left(N_z - \left(1-\frac{|U_{2k}-U_{2k+1}|}{U_{1k+1}}\right)^3\right), \qquad (9)$$

$$P_{2z}^* = \frac{(P_1^*+P_3^*)}{N_z}\cdot\left(1-\frac{|U_{2k}-U_{2k+1}|}{U_{3k+1}}\right)^3, \qquad (10)$$

where:
P_{nz}^* is the value of the tension of the fabric sample in the corresponding zone;
N_z is the number of fabric zones sounding in waves, and in which the change in the magnitude of the tension is determined, its uneven distribution (for our case $N_z = 3$).

Using the obtained expressions (9) and (10), it is possible to calculate the distribution of tension over the entire width of the controlled fabric. Figure 4b shows the distribution of tension over the three zones of the test sample 4 of knitted material from polyethylene yarn 44 Tex at different total load of the fabric. From the given Figure 4 it can be seen that the tension of the sample in its extreme zones 1 and 3, which were sounded by ultrasonic waves, increases. This can be explained by the greater deformation of the structure due to the redistribution of the thread in the extreme loops in the prototypes of rectangular knitwear under the action of the total load on the fabric. Thus, the tension distribution can be determined over the entire width of the canvas by comparing the amplitudes of ultrasonic waves from different sound zones of the sample.

Table 3.
The results of experimental studies (sample 2)

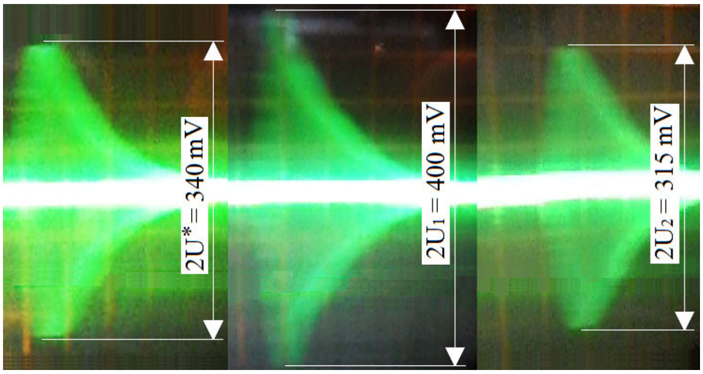
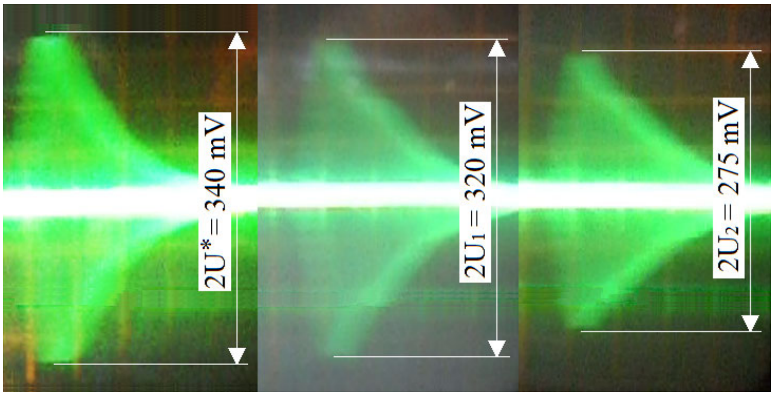
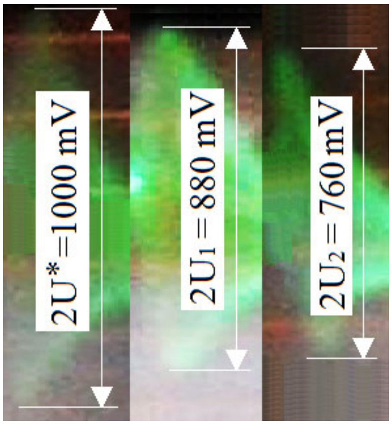
Oscillograms of voltage proportional to ultrasonic waves passing through zone 2 of the test sample 2		
		
$2U^* = 2U_{20}$ = 340 mV	$2U_1 = 2U_{21}$ = 400 mV	$2U_2 = 2U_{22}$ = 315 mV
Determination of tension by the standard method		
$P^* = 0$	P^* = 16.8 N	P^* = 28.4 N
Determination of tension by contactless ultrasonic method		
-	P^* = 13.87 N	P^* = 34.15 N
-	$\delta_P = -16.85\%$	$\delta_P = 20.26\%$
-	$\delta_U = 25\%$	$\delta_U = 14.55\%$
Oscillograms of voltage proportional to ultrasonic waves passing through zone 1 of the test sample 2		
		
$2U^* = 2U_{10}$ = 340 mV	$2U_1 = 2U_{11}$ = 320 mV	$2U_2 = 2U_{12}$ = 275 mV
Determination of tension by the standard method		
$P^* = 0$	P^* = 16.8 N	P^* = 28.4 N
Determination of tension by contactless ultrasonic method		
-	P^* = 18.03 N	P^* = 26.28 N
-	$\delta_P = 8.06\%$	$\delta_P = -7.46\%$

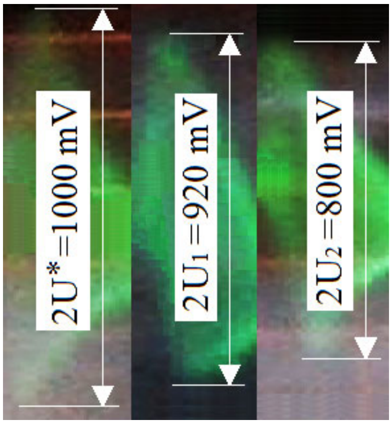
Table 4.
The results of experimental studies (sample 3)

Oscillograms of voltage proportional to ultrasonic waves passing through zone 2 of the test sample 3



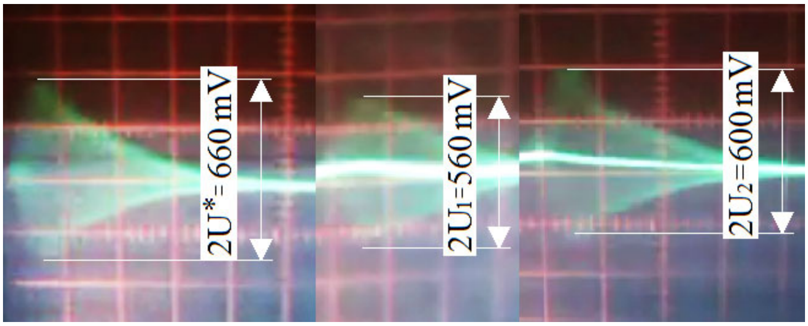
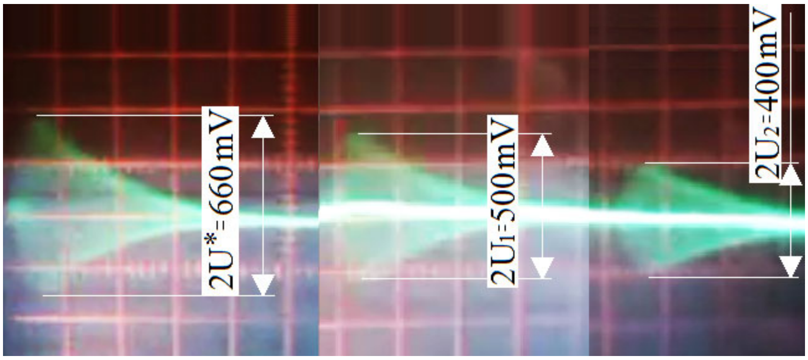
$2U^* = 2U_{20} = 1000$ mV	$2U_1 = 2U_{21} = 880$ mV	$2U_2 = 2U_{22} = 760$ mV
Determination of tension by the standard method		
$P^* = 0$	$P^* = 16.8$ N	$P^* = 28.4$ N
Determination of tension by contactless ultrasonic method		
-	$P^* = 18.29$ N	$P^* = 25.89$ N
-	$\delta_P = 9.68\%$	$\delta_P = -8.82\%$
-	$\delta_U = -4.35\%$	$\delta_U = -5\%$

Oscillograms of voltage proportional to ultrasonic waves passing through zone 3 of the test sample 3



$2U^* = 2U_{30} = 1000$ mV	$2U_1 = 2U_{31} = 920$ mV	$2U_2 = 2U_{32} = 800$ mV
Determination of tension by the standard method		
$P^* = 0$	$P^* = 16.8$ N	$P^* = 28.4$ N
Determination of tension by contactless ultrasonic method		
-	$P^* = 18.67$ N	$P^* = 25.36$ N
-	$\delta_P = 11.95$ %	$\delta_P = -10.68\%$

Table 5.
The results of experimental studies (sample 4)

Oscillograms of voltage proportional to the ultrasonic waves passing through zone 2 of the test sample 4		
 		
$2U^* = 2U_{20} = 660$ mV	$2U_1 = 2U_{21} = 560$ mV	$2U_2 = 2U_{22} = 600$ mV
-	$\delta_U = 12\%$	$\delta_U = 50\%$
Oscillograms of voltage proportional to the ultrasonic waves passing through zone 3 of the test sample 4		
 		
$2U^* = 2U_{30} = 660$ mV	$2U_1 = 2U_{31} = 500$ mV	$2U_2 = 2U_{32} = 400$ mV
Determination of tension by the standard method		
$P^* = 0$	$P^* = 16.8$ N	$P^* = 28.4$ N
Determination of tension by contactless ultrasonic method		
-	$P^* = 14.54$ N	$P^* = 32.58$ N
-	$\delta_P = -12.83\%$	$\delta_P = 14.71\%$

This presented method for determining both the total tension of fabric sample and the possibility of contactless measurement of the tension values in certain zones is a very urgent issue for light industry. Only measuring systems with contactless sensors can provide such operative tension control at each point of fabric on different textile machines.

4. Discussion

The studies have shown the implementation complexity of contactless tension control of knitted fabrics with different structure and raw materials with one setting of the contactless system for different samples of materials. This is due to the fact that, under the influence of the structure of the fabric, the through pores can both expand and decrease more in comparison with the interfibre distances of the textile material under tension. In turn, this affects the amplitude of the ultrasonic waves passing through such controlled fabrics. Therefore, the magnitude of such an amplitude of ultrasonic waves depends on the superposition of vibrations passing through the through pores of the fabric, waves passing through the interfibre distances, and waves passing through the fibres of the textile material themselves. The influence of the structure of the fabric samples on the

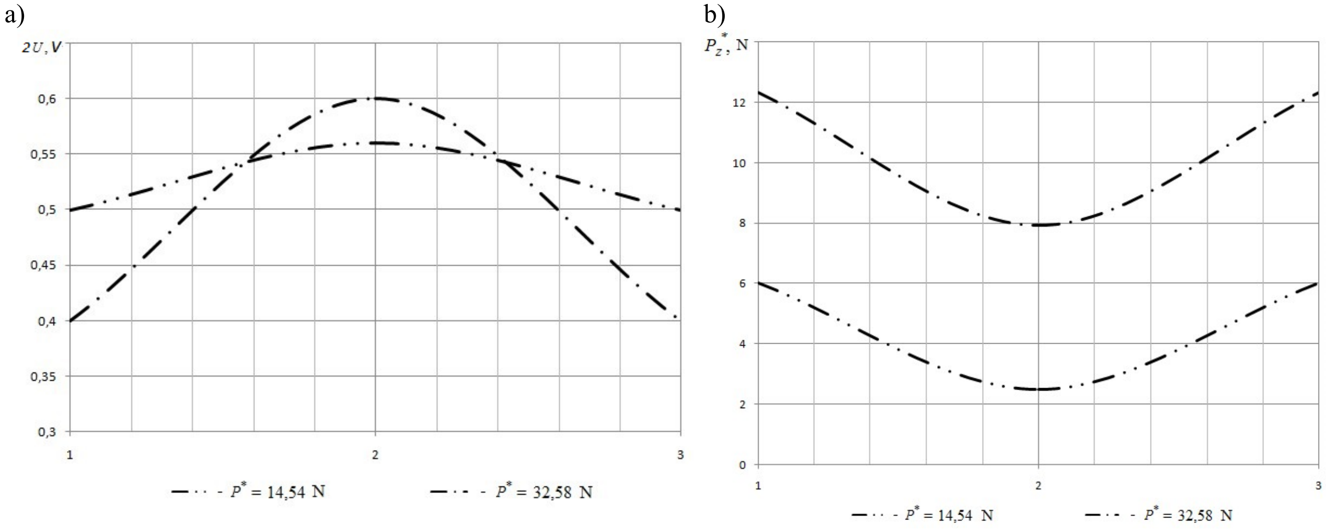


Fig. 4. Changes in voltage $2U$ proportional to the amplitude of the waves, and change in distributed tension P_z^* from zones 1, 2, 3 of the sample fabric under the action of total tension P^*: a) dependence of the voltage U from zones 1, 2, 3 of the sample fabric under tension P^*, b) dependence of the distributed tension P_z^* from zones 1, 2, 3 of the sample under tension P^*

amplitude of the probing waves can be seen on their oscillograms in Tables 2-5. For example, this effect occurs when the interaction of ultrasonic vibrations with the experimental sample 4 knitwear when sounding the second zone on the material itself, compared with other samples of knitwear made of paraaramid yarns. Due to the smoothness of the surface of polyethylene threads under the action of tension of the fabric in the second zone of the sample 4 is more intense redistribution of thread fibres at the base of the loops, as a result of which they are more deformed in the knitted structure. Therefore, first the amplitude of the waves decreases, and then with increasing tension also increases with greater deformation of the through pores. Based on these reasons, we first analysed the change in the amplitude of ultrasonic waves passing through the test material for each sample separately.

5. Conclusions

The dependence between the amplitude of the ultrasonic wave that passed through the jersey pattern and its tension is theoretically and experimentally established. Studies have shown the possibility of using contactless ultrasonic tension control of knitted fabrics to monitor the technological process of their production on knitting equipment. The proposed non-contact method consists in sounding with ultrasonic waves of a knitted fabric of double weave, forming two layers, in several of its control zones and further determination of the current value of its tension. An unknown parameter is determined by the change in the amplitude of ultrasonic waves passing through the material under the action of tension on it, which also changes during the movement of the organs of technological equipment. This non-contact method has a number of significant advantages over existing contacts and is therefore quite promising. In addition, the use of non-contact method saves a lot of money in the development of new technological equipment without the use of contact sensors to determine the tension of textile material, the adjustment of which is quite cumbersome and difficult. In the future, this will allow the integration of new contactless measuring systems to various technological equipment, which will improve the quality characteristics of finished textile fabrics and their competitiveness. Further research will be devoted to the practical application of ultrasonic non-contact method of determining tension in manufacturing textile materials of various structures, including fabrics.

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