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Non-contact Ultrasound Method of Thread Tension Determination for Light Industry Machinery

It has been established that with the help of a pulsed ultrasonic signal of complex shape, it is possible to determine the tension of a filament with a high linear density in a special waveguide with a rectangular cross-section. It has been proved that the amplitude ratios of ultrasonic waves that interact with different textile filaments are influenced by their linear density, the angle between the passage direction of part of the waves enveloping the fibers in the middle and the surface of these fibers, as well as the angle between the direction of wave propagation enveloping the thread itself from the outside, and the surface of the whole material. It should be noted that the corresponding bypass angles of the ultrasonic waves of the textile depend on the material porosity, frequency of the ultrasonic waves, and their power. To enable non-contact control of the change in the tension of the thread branch, it is advisable to use a pulsed ultrasonic signal with two different peaks of the waves, amplitudes, which are adjusted to the linear density of the thread and its conditional radius. Additionally, the use of this method will provide operational technological control in the production of textile fabrics.

Keywords: thread tension, amplitude ratios, ultrasound waves, waveguide, a linear density of thread, basis weight, textile fabrics.

Introduction

One of the most important tasks for light industry enterprises is to improve the quality of textile products and their competitiveness. Nowadays, the quality of various textile fabrics depends on the main technological parameters, the provision of which facilitates to obtain its proper level.

One of the main parameters is the basis weight of fabrics. Compliance with the appropriate basis weight of fabrics depends on the thread tension on textile machines on which fabrics are made. Due to the excessive tension of threads, their breakage on the process of equipment can occur, which leads to the lack of fabrics, downtime of textile machines, and loss of funds and time to restart them. Nowadays as the thread tension control systems on various textile machines are mostly only mechanical [1, 2], this allows to determine the actual value of this parameter in the course of such systems and to make the correct adjustments with the necessary precision, which can significantly affect the quality of the finished product.

Experimental

There are contact devices for determining the thread tension [3], but they do not allow their installation without affecting the textile material. This leads to an additional increase in tension when measuring it, which can make a significant error from the contact pressure of the sensor on the material itself. There are also optical non-contact devices for determining various parameters of threads [2, 4], but they can have significant errors due to the dustiness of the environment in the production environment.

The creation of ultrasound non-contact methods and means for determining the thread tension on different textile machines will allow operational technological control of this parameter and will provide feedback to the thread tension control systems, which will be adjusted to the actual value of this parameter. This will eliminate the shortcomings of the thread tension systems and improve the quality and competitiveness of the finished fabrics.

Results and Discussion

The movement of threads with a certain tension on the working bodies of knitting machines is the movement on guides of various shapes. If we consider such interaction of a thread with a cylindrical guide with the radius of curvature R [5], it is possible to use the amplitude ratios of ultrasound waves [6] that interact with a thread to determine the tension by changing the diameter of the thread and its density (may vary by means of reducing the interfibrous porosity of the material). In general, the dependence for determining the tension of the leading thread branch by amplitude ratios of ultrasound waves reflected from the fibers of the material to the waves that only fall on it in its interaction with the working bodies of knitting machines can be represented as follows:

$$P_1 = P_0 + (R + r^*)\left(e^{\mu_T \phi_T} - 1\right) \times \\ \times \left(R + \left(1 - \frac{P_0 \cdot (R + r^*)}{P_0 r^* + E_1 b_k \cdot (R + r^*)^2} \right) \cdot r^* \right)^{-1} \times \\ \times \left(P_0 - \frac{B_0}{2} \cdot \left(R + \left(1 - \frac{P_0 \cdot (R + r^*)}{P_0 r^* + E_1 b_k \cdot (R + r^*)^2} \right) \cdot r^* \right)^{-2} \right), \quad (1)$$

$$r^* = \frac{2Z_1 \cdot \sqrt{\dfrac{1}{|W_{Tз.}|^2} - 1}}{\pi^2 f \rho_2 \cdot \cos \nu_{з.}}. \quad (2)$$

where P_0 is the tension of the driven thread branch; P_1 is the tension of the leading thread branch; R is the radius of curvature of the cylindrical guide; Z_1 is the acoustic air resistance; f is the frequency of ultrasound vibrations; ρ_2 is the bulk density of the tread; $|W_{Tз.}| = P_{1w} / P_{01w}$ is the ratios of the pressure amplitude P_{1w} of ultrasound waves passing through the fibers of the thread material to the pressure amplitude P_{01w} of waves that just fall on it taking into account the attenuation; $\nu_{з.}$ is the angle between the direction of the part of the waves that surround the thread and its surface; r^* is the conventional radius of the thread, which is determined by the non-contact ultrasound sensor; μ_T is the coefficient of friction of the thread; ϕ_T is the angle of circumference of the thread of the guide surface; E_1 is the modulus of thread elasticity during compression; b_k is the width of trace contact thread on the guide; B_0 is the coefficient of thread rigidity when bent.

In such cases, it is necessary to use ultrasound waves that pass through the fibers of the material, as well as those that bypass the thread itself. To increase sensitivity of the sensors, it is advisable to use waveguides to determine the thread tension on different knitting machines.

Methods of control of various properties of textile fibers [7-10] do not let carry out operative technological control of the thread tension. Therefore, an amplitude method based on the developed method of controlling technological parameters of textile materials can be applied to control this parameter [11, 12]. The new method is characterized by the fact that the change in the amplitude of ultrasound waves in the waveguide determines the tension of the thread with high linear density on knitting machines.

In practice, it is advisable to use low-power sensors and corresponding waveguides to increase the sensitivity of the ultrasound waves toward the change of the diameter of the thread. Waveguides with a rectangular section are effective.

Fig. 1 represents surfaces depicting the dependence of the amplitude ratios of ultrasound waves $|W_{Tз.}|$ on the tension of the P_0 driven and P_1 leading thread branch for cotton materials, viscose threads, capron threads, wool.

Fig. 2 illustrates the surfaces that depict the dependence of the amplitude ratios of ultrasound waves $|W_{Tз.}|$ on the conventional radius of the thread r^* and the parameter $\cos \nu_{з.}$ that shows the influence of the part of the waves which surround the thread and its fibers (if large interfibrous porosity is present). It should be noted that Figures 1 and 2 show surfaces for different materials (cotton, viscose threads, capron threads, wool) which depict dependence of amplitudes of the ultrasound waves that surround the thread (since this is a large part of the ultrasound signal at which the amplitude detector of the thread tension detector captures voltage that is proportional to the amplitude of the waves transmitted to the sensor).

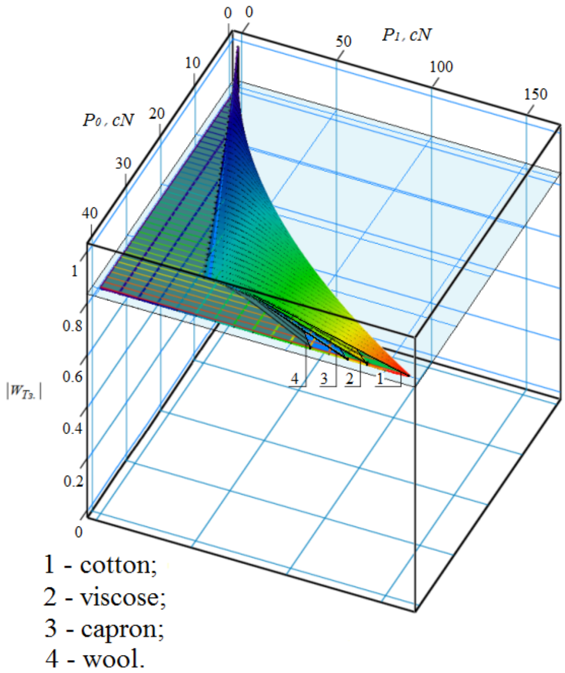


Figure 1. Surfaces showing dependence of ratios $|W_{T_{3.}}| = P_{1w} / P_{01w}$ of the pressure amplitude P_{1w} of ultrasound waves passing through the fibers of the thread material to the pressure amplitude P_{01w} of waves that just fall on material on the tension P_0 and P_1 for different threads:

1 – dependence $|W_{T_{3.}}|$ on tension parameters P_0 and P_1 for cotton;

2 – dependence $|W_{T_{3.}}|$ on tension parameters P_0 and P_1 for viscose threads;

3 – dependence $|W_{T_{3.}}|$ on tension parameters P_0 and P_1 for capron threads;

4 – dependence $|W_{T_{3.}}|$ on tension parameters P_0 and P_1 for wool.

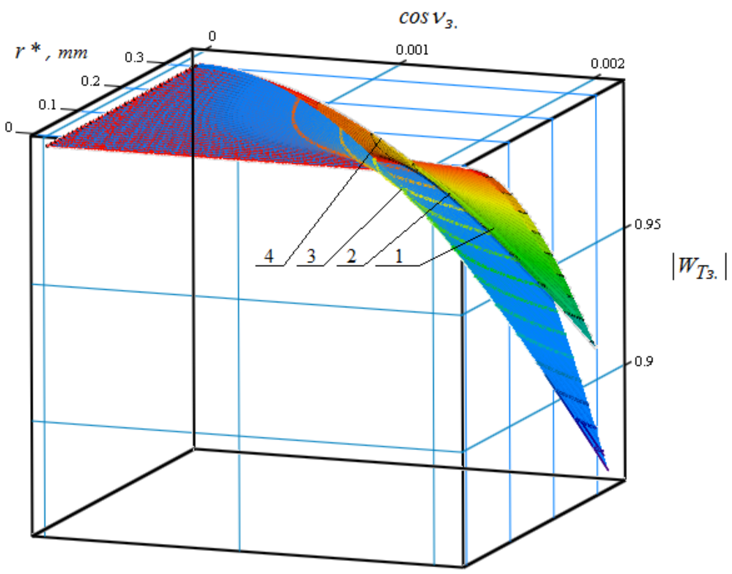


Figure 2. Surfaces showing dependence of ratios $|W_{T_{3.}}| = P_{1w} / P_{01w}$ of the pressure amplitude P_{1w} of ultrasound waves passing through the fibers of the thread material to the pressure amplitude P_{01w} of waves that just fall on material on parameters r^* and $\cos \nu_{3.}$ for different threads

These surfaces will let simplify the obtained formulas for practical implementation of non-contact means of thread tension control using special waveguides.

In the research course, it has been found out that the amplitude ratios of ultrasonic waves that interact with different textile filaments are influenced by their linear density T and parameter $\cos\nu$. It should be noted that the parameter $\cos\nu$ depends on the material porosity, the frequency f of ultrasonic waves and their power.

To have a contactless control of the tension change of the thread branch, it is advisable to use a pulsed ultrasonic signal with two different peaks of wave amplitudes (see Fig. 3), which are adjusted to the linear density T of the thread and its conditional radius r. Measuring the thread tension with the help of two peaks of wave amplitudes will allow taking into account the part of the ultrasonic signal that passes through the interfiber pores and the part of the signal that bypasses the thread itself.

If a waveguide is used to determine the tension change of a particular branch of the thread using sounding of the material with an ultrasonic pulse signal with two different peaks of amplitude, then the expression for this parameter can be written as follows:

$$P^* = \frac{P}{2}\cdot\left(\left(\frac{r}{r*}\right)^3 + \left(\frac{\cos\nu_2}{\cos\nu_2^*}\right)^3\right),$$

$$P^* = \frac{P r^3}{2}\cdot\left(\sqrt{\frac{T}{\frac{Z_1}{\pi f r n\cdot\cos\nu_1}\cdot\sqrt{\frac{1}{|W_1|^2}-1}}}\right)^{-3} +$$

$$+\frac{P}{2}\cdot\left(\frac{\pi^2 f r n \rho_2\cos\nu_2}{Z_1}\right)^3\cdot\left(\sqrt{\frac{1}{\left(|W_2| - \frac{P_{1w}}{K_V P_{01w}^*}\right)^2}-1}\right)^{-3}, \tag{3}$$

$$P^* = \frac{P r^3}{2}\cdot\left(\sqrt{\frac{T}{\frac{Z_1}{\pi f r n\cdot\cos\nu_1}\cdot\sqrt{\left(\frac{U_1}{U_i}\right)^2-1}}}\right)^{-3} +$$

$$+\frac{P}{2}\cdot\left(\frac{\pi^2 f r n \rho_2\cos\nu_2}{Z_1}\right)^3\cdot\left(\sqrt{\frac{1}{\left(\frac{U_i^*}{U_1^*} - \frac{U_i}{K_V U_1^*}\right)^2}-1}\right)^{-3},$$

$$K_V = K_p^{\left(\frac{P_{01w}}{P_{1w}}\right)} = K_p^{\left(\frac{U_1}{U_i}\right)}, \tag{4}$$

$$\delta = \frac{P^*(\text{using ultrasonic method measurement}) - P^*(\text{using standard contact method measurement})}{P^*(\text{using standard contact method measurement})}\cdot 100\%, \tag{5}$$

where i – 2, 3, 4…, the number of the voltage amplitude value from the receiving transducer when changing the thread branch tension as for its previous state; U_1 – the voltage amplitude which is proportional to the smaller peak of the pulsed ultrasonic signal when it propagates in the waveguide without a thread; U_i – the voltage amplitude which is proportional to the smaller peak of the pulsed ultrasonic signal when it propagates in a waveguide with a thread with a change in its tension, different values of which are associated with the sequence number i; U_1^* – the voltage amplitude which is proportional to the larger peak of the pulsed ultrasonic signal when it propagates in the waveguide without a thread; U_i^* – the voltage amplitude which is proportional to the larger peak of the pulsed ultrasonic signal, when it propagates in a waveguide with a thread with a change in its tension, the different values of which are associated with the sequence number i; $|W_1|$ – module of complex coefficient of ultrasonic waves transmission which is equal to the voltage ratio U_i / U_1; $|W_2|$ – module of complex coefficient of ultrasonic waves transmission which is equal to the voltage ratio U_i^* / U_1^*; ν_1 – the angle between the direction of the waves enveloping the thread fibers in its middle, and the surface of these fibers; ν_2 – the angle between the direction of the part of the waves that envelop the thread from its outer side, and the surface of the whole material; ν_2^* – the angle between the direction of the part of the waves that envelop the thread from its outer side, and the surface of the whole material when changing the fibers tension; r – conventional radius of the controlled thread in case of the absence of tension; n – the number of the ultrasonic wave passes of the cross section of the waveguide with the thread which is necessary for the oscillations to enter the receiving transducer; K_V – the ratio of the air volume between the thread fibers; K_p – initial coefficient of interfiber porosity of the thread material; T – linear thread density; P – initial thread tension; P^* – the current tension of the thread being determined; P_{01w} – the pressure amplitude in the wave of the smaller peak of the pulse signal that passes through the waveguide without a thread; P_{1w} – the pressure amplitude in the wave of the smaller peak of the pulse signal that passes through the waveguide with the thread when changing its tension; P_{01w}^* – the pressure amplitude in the wave of the larger peak of the pulse signal that passes through the waveguide without a thread.

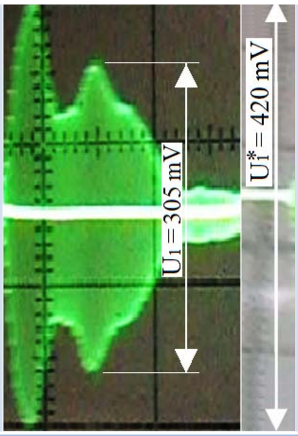
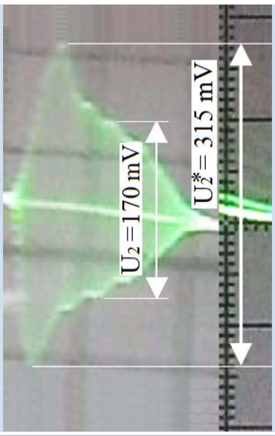
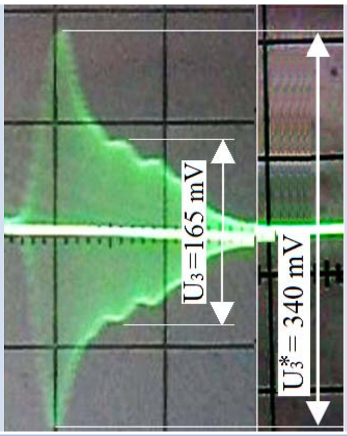
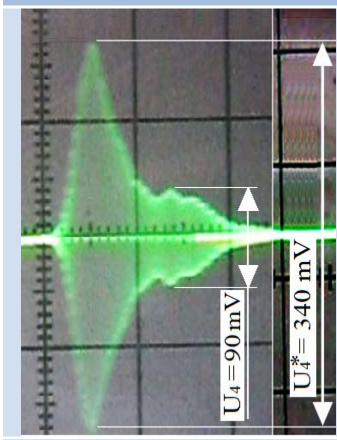
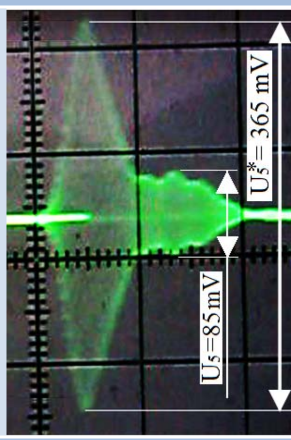
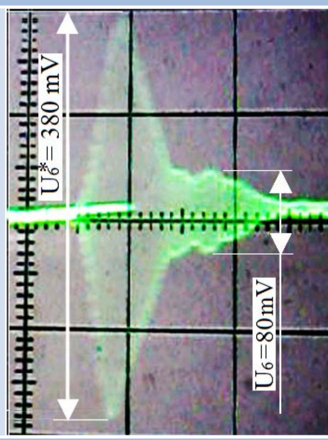
By means of the received aspect (3), it is possible to define in practice a change of current thread tension with a big linear density on the technological equipment if necessary. It is also possible to further investigate the change in the interfiber porosity of different threads during their tension.

Some results obtained in theoretical and experimental studies are represented in Table 1.

Table 1

Experimental data of non-contact method

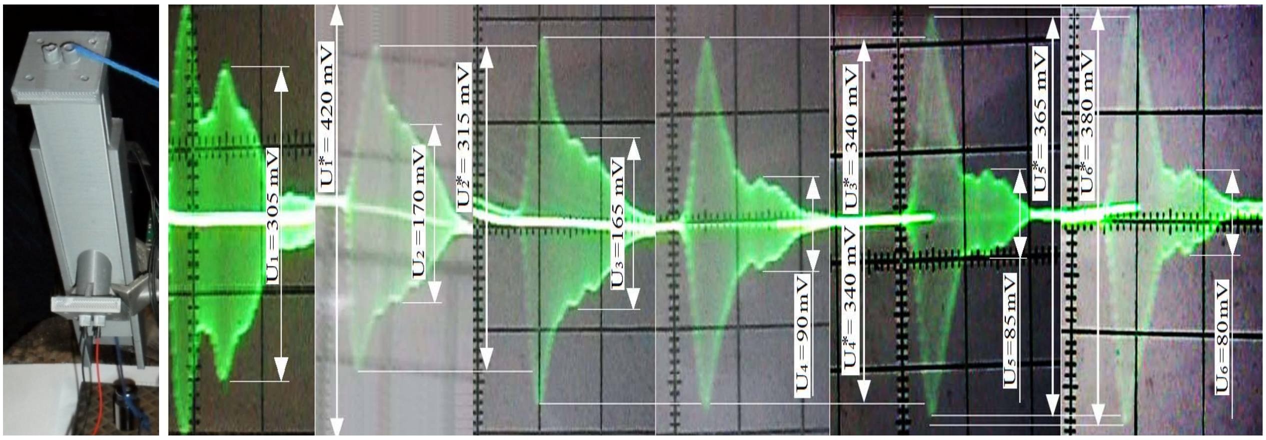
Parameter	Experimental data		
T	445 mg/m		
r	1.50 mm		
f	40 kHz		
$\cos \nu_2$	0.00335		
K_p	2.8		
P	19.6 cN		
n	3		
i	-	2	3
Determining P^* using contact method:	-	0	19.6 cN
r^*	-	1.50 mm	1.47 mm
$\cos \nu_2^*$	-	0.00335	0.00334

Voltage oscillograms			
Voltage amplitude	U_1 = 305 mV U_1^* = 420 mV	U_2 = 170 mV U_2^* = 315 mV	U_3 = 165 mV U_3^* = 340 mV
$\lvert W_1 \rvert = \frac{U_i}{U_1}$	1	0.557	0.541
$\lvert W_2 \rvert = \frac{U_i^*}{U_1^*}$	1	0.750	0.810
Determining P^* **using non-contact method:**	-	0	20.364 cN
Variance δ	-	0	3.9 %
i	4	5	6
Determining P^* **using contact method:**	49.0 cN	68.6 cN	98.0 cN
r^*	1.02 mm	0.99 mm	0.95 mm
$\cos \nu_2^*$	0.00282	0.00222	0.00183
Voltage oscillograms			
Voltage amplitude	U_4 = 90 mV U_4^* = 340 mV	U_5 = 85 mV U_5^* = 365 mV	U_6 = 80 mV U_6^* = 380 mV
$\lvert W_1 \rvert = \frac{U_i}{U_1}$	0.295	0.279	0.262
$\lvert W_2 \rvert = \frac{U_i^*}{U_1^*}$	0.810	0.869	0.905
Determining P^* **using non-contact method:**	47.904 cN	68.333 cN	98.544 cN
Variance δ	-2.2 %	-0.39 %	0.56 %

These results show that it is possible to create an accurate non-contact method for determining the thread tension with a high linear density.

The part of the ultrasound signal, which passes directly through the structure of the thread itself, can also be used to determine the change of interfibrous porosity of the threads. The effect of determining the change of interfibrous porosity in the thread tension process has also been considered in this article and has been experimentally recorded by using ultrasound impulse signals of a complex shape, as shown in Table 1. and Fig. 3.

Non-contact determination of the thread tension using a waveguide, with all oscillograms of pulsed ultrasonic signals are represented in Fig. 3. The correspondence of each oscillogram of pulse signals to the current value of the thread tension in the waveguide is noticed. It is clear that the first peak of the amplitude of the ultrasonic signal decreases, and the second peak of the amplitude increases. The combination of measuring information about the amplitude informative parameters of the two peaks of ultrasonic waves makes it possible to consider the part of the oscillations that bypasses the controlled material and to reduce the error of tension measurement.



No thread P = 0 P = 19,6 cN P = 49,0 cN P = 68,6 cN P = 98,0 cN

a **b**

Figure 3. Non-contact determination of thread tension in a waveguide:

a – transmission of an impulse ultrasound signal through a thread in a waveguide without repetition;
b – appearance of an impulse ultrasound signal of a complex shape with two peaks of amplitudes which determine tension and change of interfibrous porosity of the thread after passing through and repetition of waves in a waveguide

The increase of the second peak amplitude of an ultrasound signal of a complex shape indicates increase in the magnitude of tension and decrease of a nominal diameter of the thread in accordance with the surfaces illustrated in Fig. 2, and the decrease of the first peak amplitude of an ultrasound signal shows decrease of interfibrous porosity of the thread with increasing its tension and deformation.

Figure 4 graphically demonstrates the theoretical dependencies and experimental data, which were also given in Table 1. From the obtained data parameters, one can see that in the area of the curve when the thread tension is in the range from 20 cN to 50 cN, its diameter and interfiber porosity decrease significantly. At the beginning of the thread tension process, when the interfiber porosity is significant, some of the waves pass through the pores between the fibers, so the higher peak of the amplitude is further increased. At a tension of 50 cN, the higher peak of the amplitude increases due to the part of the waves enveloping the thread with a reduced diameter from the outside of its surface. The other part of the oscillations, which initially further increased the amplitude of this peak, now passing through the reduced pores between the fibers of the material from the middle, reduces the resulting amplitude. Therefore, Figure 4 represents that the amplitude of this peak during the action of the thread tension in this range of its values (20 cN – 50 cN) remains the same.

Studies have shown that with the help of impulse ultrasound signals it is possible to determine not only the tension of threads with high linear density but also the degree of twist of complex threads by changing their interfibrous porosity, which, in turn, can be controlled by changing the amplitudes of ultrasonic waves.

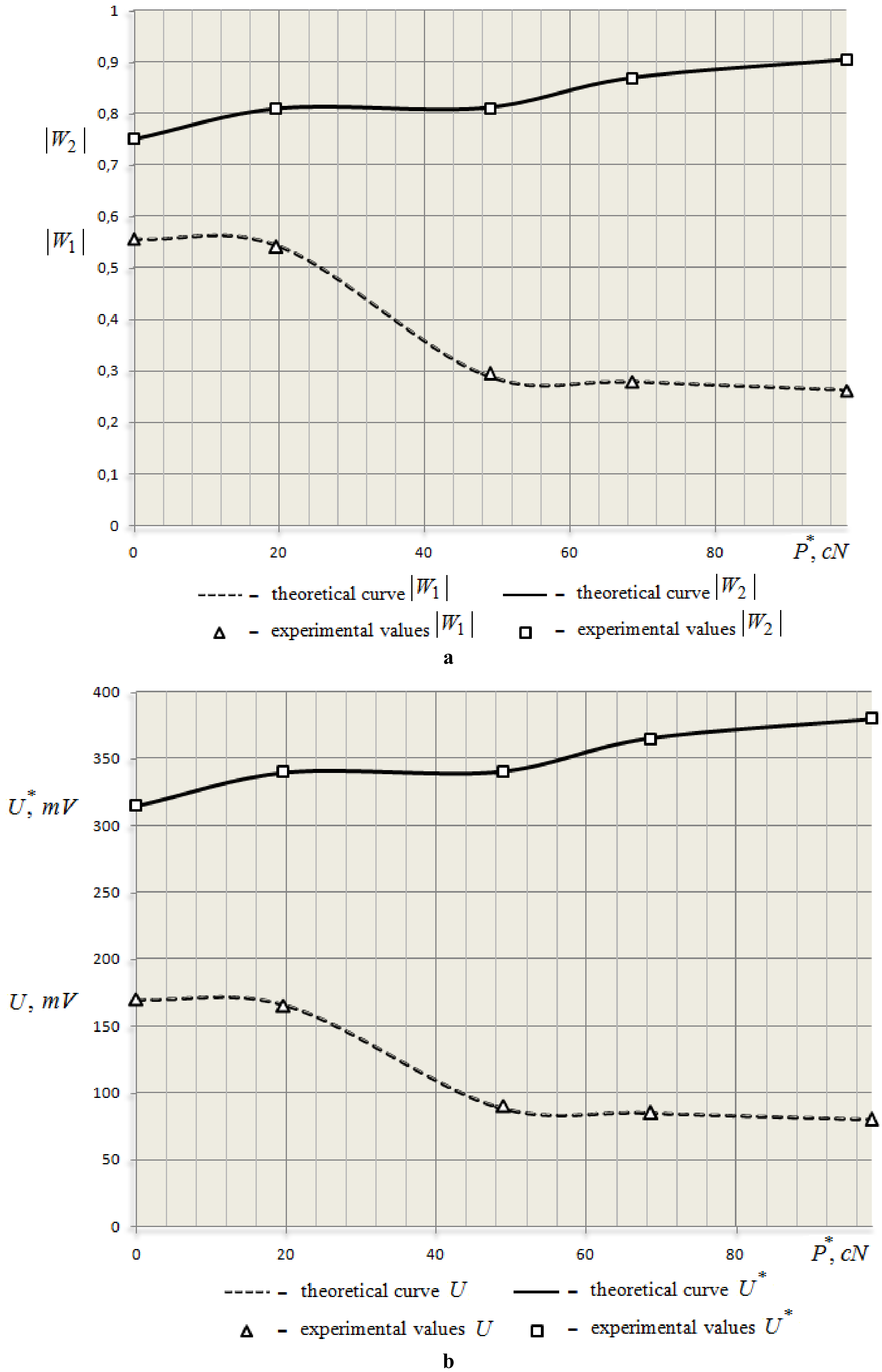


Figure 4. Dependencies of amplitude parameters on the thread tension in the waveguide:
a – dependencies of amplitude parameters $|W_1|$, $|W_2|$ waves on the thread tension P^*;
b – dependencies of the amplitude voltages parameters U_i, U_i^* on the thread tension P^*

The amplitude ratios of ultrasonic waves that interact with the thread material, make it possible to create contactless control systems of the thread tension for the production of textile fabrics.

Conclusions

In the course of the research, it was found out that impulse ultrasound signals can be used to determine the thread tension of different raw material composition. A pulsed ultrasonic signal of complex shape allowed to determine the tension of a filament with a high linear density in a special waveguide with a rectangular cross-section. To enable non-contact control of the change in the tension of the thread branch, the use of a pulsed ultrasonic signal with two different peaks of the wave amplitudes were adjusted to the linear density of the thread and its conditional radius. It was possible to see from the general comparison of pulse signals correspondence of each of their oscillogram to current value of a tension of a thread in a waveguide. During the non-contact determination of thread tension in a waveguide the first peak of the amplitude of the ultrasonic signal decreased, and the second peak of the amplitude increased. The combination of measuring information about the amplitude informative parameters of the two peaks of ultrasonic waves implemented to consider the part of the oscillations that bypasses the controlled material and to reduce the error of tension measurement. An increase in the amplitude of the second peak of the ultrasonic signal of complex shape showed an increase in tension and a decrease in the conditional diameter of the thread, and a decrease in the amplitude of the first peak of the ultrasonic signal demonstrated a decrease in interfiber porosity with increasing tension and deformation. From the obtained data on the amplitude parameters of ultrasonic waves, in the area of the curve graph, when the tension of the filament was in the range from 20 cN to 50 cN, its diameter and interfiber porosity significantly decreased. At the beginning of the thread tension process, when the interfiber porosity was significant, the part of the waves passed through the pores between the fibers, so the higher peak of the amplitude was further increased. At a tension of 50 cN, the higher peak of the amplitude increased due to the part of the waves enveloping the thread. The other part of the oscillations, which initially further increased the amplitude of this peak, then passed through the reduced pores between the fibers of the material from the middle, reduced its resulting amplitude. Therefore, the amplitude of this peak during the action of tension on the thread in this range of its values (20 cN – 50 cN) remained the same. Conducted research will facilitate to use non-contact ultrasound methods and means for the operating control of the thread tension in the process of production of various textile fabrics. In the future, it will improve the quality by maintaining within the regulated limits of basis weight of the fabrics with the required accuracy, as well as the competitiveness of domestic products in textile industry.

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В.Г. Здоренко, В.Ю. Кучерук, С.В. Барылко, С.Н. Лисовец

Жеңіл өнеркәсіп машиналары үшін жіптің керілуін анықтайтын байланыссыз ультрадыбыстық әдіс

Күрделі пішінді импульсті ультрадыбыстық дабылды қолдана отырып, тікбұрышты қимасы бар арнайы толқын өткізгіште жоғары сызықтық тығыздығы бар жіптің керілуін анықтауға болатындығы анықталды. Әртүрлі тоқыма жіптерімен өзара әрекеттесетін ультрадыбыстық толқындардың амплитудалық қатынасына олардың сызықтық тығыздығы, жіп талшықтарын оның ортасында айналдыратын толқындардың бір бөлігінің өту бағыты мен осы талшықтардың беті арасындағы бұрыш, сондай-ақ жіптің сыртқы жағынан айналатын толқындардың бір бөлігінің таралу бағыты мен бүкіл материалдың беті арасындағы бұрыштың әсер ететіндігі дәлелденді. Тоқыма бұйымдарына ультрадыбыстық толқындарының сәйкес өту бұрыштары материалдың кеуектілігіне, ультрадыбыстық толқындардың жиілігіне және олардың қуатына байланысты екенін атап өткен жөн. Ультрадыбыстық толқындардың амплитудалық қатынасының жіптің керілуіне алынған тәуелділіктерінің графигі және оларды тәжірибелік мәліметтермен салыстыру берілген. Жіп тармағының керілуінің өзгеруін байланыссыз басқару мүмкіндігі үшін жіптің сызықтық тығыздығына және оның шартты радиусына сәйкес келетін екі түрлі толқындық амплитудасы бар импульсті ультрадыбыстық дабылды қолданған жөн. Сонымен қатар, әдісті қолдану тоқыма маталарды өндіру кезінде жедел технологиялық бақылауды қамтамасыз ететіні көрсетілді. Аталған байланыссыз ультрадыбыстық әдіс тоқу машиналарында жіптердің керілуін реттеу жүйесін жетілдіруге, сондай-ақ өндіріс кезінде олардың үзілгенін анықтауға көмектеседі. Бұл өз кезегінде технологиялық жабдықтардың тоқтап қалуын қысқартады, дайын өнімнің сапасын жақсартады және оның нарықтағы бәсекегеқабілеттілігін қамтамасыз етеді.

Кілт сөздер: жіптің тартылуы, амплитудалық коэффициенттер, ультрадыбыстық толқындар, толқын өткізгіш, жіптің сызықтық тығыздығы, бетінің тығыздығы, тоқыма маталар.

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Бесконтактный ультразвуковой метод определения натяжения ниток для машин легкой промышленности

Установлено, что с помощью импульсного ультразвукового сигнала сложной формы можно определять натяжение нити с большой линейной плотностью в специальном волноводе с прямоугольным сечением. Доказано, что на амплитудные соотношения ультразвуковых волн, которые взаимодействуют с различными текстильными нитями, влияют их линейная плотность, угол между направлением прохождения части волн, огибающих волокна нити в ее середине, и поверхностью этих волокон, а также угол между направлением распространения части волн, огибающих нить с внешней ее стороны, и поверхностью всего материала. Следует отметить, что соответствующие углы обхода ультразвуковых волн текстиля зависят от пористости материала, частоты ультразвуковых волн и их мощности. Приведены графики полученных зависимостей амплитудных соотношений ультразвуковых волн от натяжения нити и их сравнение с экспериментальными данными. Для возможности бесконтактного контроля изменения натяжения ветви нити целесообразно применять импульсный ультразвуковой сигнал с двумя различными пиками амплитуд волн, которые настраиваются под линейную плотность нити и ее условный радиус. Показано, что использование этого метода позволит обеспечить оперативный технологический контроль в процессе производства текстильных полотен. Данный бесконтактный ультразвуковой метод поможет улучшить систему регулирования натяжения нитей на трикотажных машинах, а также определять их обрывность в процессе производства. Это, в свою очередь, уменьшит простой технологического оборудования, повысит качество готовой продукции и обеспечит ее конкурентоспособность на рынке.

Ключевые слова: натяжение нити, амплитудные соотношения, ультразвуковые волны, волновод, линейная плотность нити, поверхностная плотность, текстильные полотна.

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