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DETERMINING THE RATIONAL STRUCTURE OF MULTILAYER TECHNICAL FABRIC FOR WOVEN POWER CLAMPS

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The object of research is multi-layered technical fabrics for woven power clamps. A task to determine the rational structure of a multi-layer technical fabric for power clamps has been solved, which makes it possible to achieve an effect when introduced into production through the minimization of raw material costs and the reduction of energy costs for manufacturing a unit of products. The value of the beating force, the tension of warp threads of the outer protective layers, the force layers, the warp threads for connecting the outer protective layers, and the force layers for two structures of multilayer technical fabric were studied. A comparative analysis of conditions for the formation of two multilayer fabrics from polyamide threads was carried out and a multilayer fabric with the most rational structure was selected, the formation of which would require less technological effort. Experimental studies have made it possible to build regression dependences on determining the influence of the initial tension of warp threads of the outer protective layers on the beating force value. The joint effect of the size of an overstep and the different tension of a shed on the beating force value was established, depending on the structure of a multilayer technical fabric. It is shown that when the tension of warp threads of the outer protective layers increases, the beating force value increases. A value of the tension of warp threads in outer protective layers, force layers, warp threads for connecting the outer protective layers and force layers in the position of an overstep and at the moment of thread beating was determined. Analysis of regression dependences will make it possible to determine the optimal loading parameters of the loom. It has been proven that the beating force value is affected by the structure of a multi-layer technical fabric and the tension of warp threads in outer protective layers. The improved multi-layer technical fabric is used for laying pipes with an external factory-made polyethylene coating

Keywords: woven power clamps, multi-layer technical fabric, beating force, thread tension

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1. Introduction

Pipes with external factory-made polyethylene coating are used in the construction and commissioning of main oil and gas pipelines. Factory insulation of pipes allows for reliable protection against corrosion. The polymer coating prevents the formation of rust and premature wear of steel infrastructure. Anti-corrosion protection is applied to steel pipelines, which are laid underground or in high humidity. Constant contact with wet soil, air, and water can lead to rapid damage of metal products. Polymer factory insulation protects the metal from contact with aggressive external environments and increases the service life of the pipeline several times. Compared to coating pipes with insulating material directly on the route, the introduction of factory pipe insulation technology not only made it possible to accelerate the pace of construction of pipelines but also to significantly improve the effectiveness of their anti-corrosion protection. In both the first and second cases, chains and cables cannot be used to hold and lay pipes with an external factory insulating coating. A large specific pressure in the contact zone leads to the destruction of the insulating coating, which causes metal corrosion when the areas with the destroyed insulation are in contact with water and soil.

For laying pipes with a factory insulating coating, woven power clamps are used, which are made of multi-layer technical fabrics. The structure of a multilayer technical fabric and the conditions of its formation on the loom determine the efficiency of the process of manufacturing woven power clamps.

The woven power clamp is a closed loop made of multilayered technical fabric. The outer surface of the clamp is in contact with the surface of the ground and the insulating coating of the pipe. Of great importance is the process of friction of the surface of a woven power clamp with these surfaces. When the weight of the pipe increases, the clamp width can increase. The tension of fabric formation process is determined by the beating force value, which, in turn, determines the strength of resistance to the movement of all weft threads in the zone of multilayer fabric formation. This allows us to state that the structure of a multilayer technical fabric affects the conditions of its formation. It also makes it possible to enable the entire set of physical, mechanical, and consumer properties, as well as obtain an effect when introduced into production through the minimization of raw material costs, reduction of energy costs for the production of a unit of products.

In this regard, it is a relevant task to investigate the rational structure of multilayer technical fabric for power clamps.

2. Literature review and problem statement

In work [1], from the standpoint of the spatial geometry of multilayer fabrics and the internal arrangement of threads relative to the axis of the fabric, the forces and deformations in the binding elements of woven materials, the transverse deformation of threads when an external load is applied, are determined. However, the issue of determining the influence of tension of warp threads, the size of the overstep and different tension of shed on beating force value during the formation of multilayer fabrics is not considered. In work [2], the structures of woven power clamps for laying pipes with a factory insulating coating, which are made of multilayer technical fabrics, are presented. It is determined that the multilayer technical fabric consists of two protective layers, two force layers, and a separation layer, which is formed by interweaving weft threads and warp threads to connect the outer protective layers. The main element of a woven power clamp is warp threads of force layers. The outer protective layers are designed to protect the force layers. The cited work lacks data on the influence of the structure of multilayer technical fabric, the technique of connecting fabric layers to each other on the magnitude of the beating force – the main technological factor that determines the intensity of the process of forming multilayer technical fabric.

Work [3] investigates the influence of the rational structure of multilayer fabric on providing the entire set of physical and mechanical, consumer properties with the minimum necessary consumption of raw materials, energy costs for the production of a unit of products, by modeling the physical and mechanical properties of a textile product. The work lacks research into the process of forming multilayer technical fabrics for power clamps, which are used when laying pipes with a factory insulating coating, in particular, determining the influence of tension of warp threads on the magnitude of the beating force. Analogs for designing the structure of multilayer technical fabrics are multilayer fabrics made of polyamide-polyester materials of belt conveyors [4], carrying elements using composites with textile reinforcement with different cord angles and an elastic matrix [5]. The mechanical properties of multilayer technical fabrics depend on the interweaving of the main and weft threads, the number of layers. In the cited works, there are no data on the influence of structure of the multilayer technical fabric for power clamps on the magnitude of the beating force that occurs during the movement of the weft thread in the zone of formation of the multilayer fabric. This predetermines the intensity of the process that forms a multilayer technical fabric.

Work [6] reports the results of determining technological efforts during the formation of a multilayer fabric on a machine, which made it possible to determine the influence of the degree of different tension of the shed, the filling tension on the strength of the weft thread. There are no studies into the influence of structure of multilayer technical fabric for power clamps, the technique of tying the fabric layers together, the preliminary tension of warp threads in protective layers on the beating force value. Determining the function of change in the tension of main threads over the fabric element formation cycle makes it possible to evaluate the working conditions of threads under multi-cycle loads, the degree of intensity of the processes of interaction of threads with the guide and working bodies of the loom [7].

The change in the amount of thread tension along the filling depth of the technological device depends on the conditions of its interaction with the guide and working bodies of small and large curvature. Work [8] investigated the factors that affect the amount of tension of main threads on the depth of filling of the loom. It was established that when interacting with guide surfaces of large curvature, it is necessary to take into account the influence of the stiffness of the main thread on bending, the value of the actual angle of coverage of the main thread of the guide of large curvature, the pre-tension of the main thread. In [9], the sequence of using the recursion algorithm to determine the law of change in the tension of the main thread along the depth of the filling of the loom, taking into account the deformation of the thread in the contact zone with the guide, the stiffness of the thread on bending, and the amount of pretension is given. The work does not contain data on the formation of multilayer fabrics, for the manufacture of which two or more yarns with the main threads of protective layers are used, the tension of which affects the magnitude of the beating force. Taking into account the direction of the relative movement of the surfaces of the thread and guide, the deformation of thread in the contact zone with the guide of great curvature, the radial coverage of the thread by the surface of the guide makes it possible to determine the amount of tension in the working zone of fabric formation [10].

Paper [11] investigates the distribution of bond forces through the points of connection of the main and weft threads in woven layers, which leads to anisotropy of the structural properties of multilayer fabrics. The existing frictional forces hold the fibers of the main and weft threads under the external load of the multilayer fabric element. The research data are static and cannot be used for dynamic analysis of the process of forming multilayer technical fabrics for power clamps directly on the machine. A special place belongs to studies on determining a change in the tension of main threads when interacting with the eyes of the galley frames, when the angle of radial coverage of the thread by the surface of the guide is not equal to zero [12]. This type of interaction also occurs when the weft thread is moved in the zone of multilayer fabric formation. The presence of deformation of the complex thread in the contact zone with the guide is explained by its small twist [13]. As a result of twisting, the structure and, therefore, various parameters and properties of the bundle of threads change. As the twist ratio increases, the twist of the twisted multifilament yarn increases, while the diameter of the yarn decreases, and the packing density increases. The strength had a tendency to decrease with an increase in the twist ratio [14]. An increase in the tension in the filling zones of the loom leads to an increase in the number of breaks in the main threads. This leads to a stoppage of the equipment and the appearance of defects in the weaving cloth in the form of transverse striations, an increase in the percentage of cut-off of defective areas of the cloth [15].

A separate group is represented by research into the experimental determination of the tension of main threads during their interaction with guide surfaces. In work [16], a device is used to determine the tension, which makes it possible to change the initial tension, the value of the angle of coverage of the base of the guide thread by the thread. Of special importance is the dynamic analysis of the process of thread interaction with the guide surface not only in longitudinal but also in transverse sliding [17]. In work [18], when experimentally determining the tension of main threads with guides, its kinematic characteristics are taken into account, which are determined by the specificity of the technological process itself. In work [19], in the experimental setup, the guide surface was installed with the possibility of rotation about its axis. Moreover, the radius of curvature of the guide significantly exceeded the calculated radius of the main thread. The results cannot be used to analyze the conditions for the formation of multilayer fabrics since the experimental conditions did not correspond to the actual conditions of interaction between the warp and weft threads. The tension of warp threads in front of the multilayer fabric formation zone consists of the filling tension and the additional tension that arises due to the friction forces of warp threads against the surface of the guide and working bodies of the loom. Work [20] considered the possibility of modeling the process, which allows the determination of the amount of tension after the guide, taking into account the real conditions of processing of main threads on technological equipment. The work lacks research into the process of forming multilayer technical fabrics for power clamps, which are used when laying pipes with a factory insulating coating, in particular, determining the effect of tension of warp threads in protective layers on the magnitude of the beating force.

Our systematic review of the literature has made it possible to determine the main issues that need to be resolved in the development of a rational structure of multilayer technical fabric for woven power clamps. These tasks include the influence of the structure of multilayer technical fabric on the amount of technological effort during its formation on a loom; determination of the influence of the initial tension of warp threads in protective layers on the magnitude of beating force for multilayer technical fabric; determination of the joint influence of the overstep and different tension of the shed on beating force for multi-layered technical fabric.

3. The aim and objectives of the study

The purpose of our study is to determine the rational structure of multilayer technical fabric for power clamps. This makes it possible to enable the entire set of physical, mechanical, and consumer properties and to obtain an effect when introduced into production through the minimization of raw material costs and the reduction of energy costs for the production of a unit of products.

To achieve the goal, the following tasks must be solved:

– to determine the influence of the initial tension of warp threads in protective layers on the magnitude of beating force for the multilayer technical fabric MTF-2;

– to determine the influence of the initial tension of warp threads in protective layers on the beating force value for the multilayer technical fabric MTF-6;

– to determine the joint effect of the overstep and different tension of the shed on the beating force value for the multilayer technical fabric MTF-2;

– to determine the joint influence of the overstep and different tension of the shed on the beating force value for the multilayer technical fabric MTF-6.

4. The study materials and methods

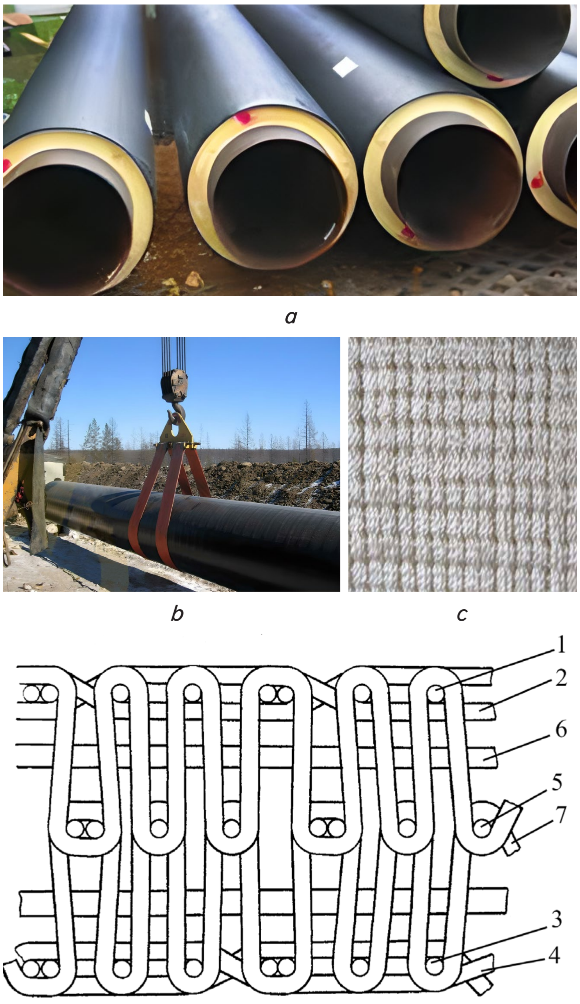
The object of research was the technological process of weaving. The subject of our study was the structure of multilayer technical fabrics for power clamps. Assumptions in the work related to the filling tension of main threads. A decrease in the filling tension led to sagging of the warp threads in the zone of formation of multilayer technical fabric, and an increase in the filling tension led to massive breaks. For the multilayer technical fabric MTF-2, the initial tension of warp threads in protective layers varied from 169.4 cN to 228.2 cN. For the multilayer technical fabric MTF-6, the initial tension of warp threads in protective layers varied from 97.3 cN to 133.0 cN. This also applied to the magnitude of the overstep and the vertical shift of the upper point of the warp guide relative to the average position. For the multi-layer technical fabric MTF-2, the amount of overstep varied from 20 to 40 degrees. Different tension of the shed was created with the help of a vertical shift of the upper point of the warp guide relative to the middle position. This value varied from 10 to –10 mm. A minus sign indicates that the warp guide has fallen below the average position. For the multi-layer technical fabric MTF-6, the amount of overstep varied from 10 to 20 degrees.

During the construction of main oil and gas pipelines, pipes with a factory external insulating coating are used (Fig. 1, *a*). Factory insulation of pipes allows for reliable protection against corrosion. The polymer coating prevents the formation of rust and premature wear of steel infrastructure. For laying pipes with a factory insulating coating, woven power clamps (Fig. 1, *b*) are used, which are made of multilayer technical fabrics. The woven power clamp is a closed loop element made of multilayer technical fabric with a width of 20 cm. The structure of the multilayer technical fabric and the conditions of its formation on the loom determine the efficiency of the process of manufacturing woven power clamps.

Our paper considers two multilayer technical fabrics MTF-2 and MTF-6. The MTF-6 multilayer technical fabric is an improved version of the prototype MTF-2 multilayer technical fabric. These multi-layer technical fabrics differ in their structure. In the multi-layer technical fabric MTF-2, additional warp threads are used to bind the outer protective layers and force layers. In the multilayer technical fabric MTF-6, the connection between the protective and force layers is enabled by warp threads of the outer protective layers.

An ATM-type automatic loom with a carriage for forming a shed on 8 strict frameworks was used for the production of MTF-2 fabric. The warp threads are located on three warp beams, which significantly complicates the maintenance of the loom. The different deformation of warp threads requires the creation of a different initial tension for each type of warp threads. An ATM-type automatic loom with a carriage for forming a shed on 8 strict frameworks was used for the production of MTF-6 fabric. The warp threads are located on two warp beams.

In the first case, the multilayer technical fabric MTF-2 was used for a woven power clamp (Fig. 1, *d*). This fabric consists of 5 layers. Fig. 1, *d* shows a section of the fabric along warp threads.



a

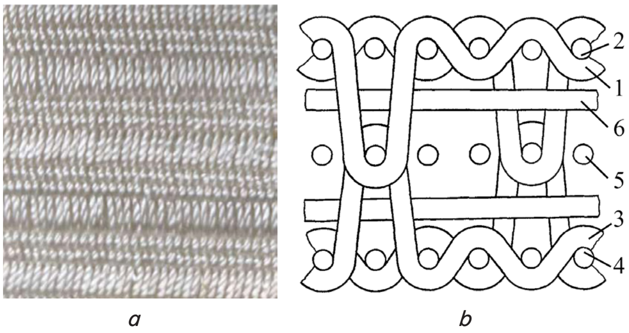
b *c*

d

Fig. 1. Components of the construction process of main oil and gas pipelines: *a* — pipes with factory-made external insulating coating; *b* — woven power clamps; *c* — general appearance of the multilayer technical fabric MTF-2; *d* — section of MTF-2 fabric along warp threads; 2, 4 — warp threads of the outer protective layers (PL); 6 — warp threads of force layers (FL); 7 — warp threads for binding external protective layers and force layers (BIN); 1, 3, 5 — weft threads

The main element of a woven power clamp is the warp threads in force layers (FL). The outer protective layers are designed to protect the force layers. For the MTF-2 fabric (width 20 cm), 816 polyamide complex threads 29 Tex high twist S110x2 S300 Z 180 were used as warp threads in outer protective layers (PL). 544 polyamide complex threads 93.5 Tex S were used as warp threads in force layers (FL) 30 Z 60. 136 polyamide complex threads 29 Tex S110x2 S300 Z 180 were used as warp threads for binding the outer protective layers and force layers (BIN). 240 polyamide complex threads 29 Tex S110x2 S300 Z 180 were used as weft threads per decimeter. The weft weave rapport is 24. The total strength of warp threads in the fabric is 53,400 N. The breaking load of a strip of MTF-2 fabric with a width of 50 mm is 41,100 N. The breaking elongation is 54 %. The weight of 1 meter of MTF-2 fabric is 490 cN.

In the second case, the multilayer technical fabric MTF-6 was used for a woven power clamp (Fig. 2, *a*). This fabric consists of 5 layers. Fig. 2, *b* shows a section of the fabric along the warp threads.



a *b*

Fig. 2. Multi-layer technical fabric MTF-6: *a* — general view; *b* — section of the fabric along warp threads; 1, 3 — warp threads of outer protective layers (PL); 6 — warp threads of force layers (FL); 2, 4, 5 — weft threads

For the MTF-6 fabric (width 20 cm), 744 polyamide complex threads 29 Tex of high twist S110x2 S300 Z 180 were used as the warp threads of outer protective layers (PL). 744 polyamide complex threads 93.5 Tex S were used as the warp threads of force layers (FL) 30 Z 60. 100 polyamide complex threads 93.5 Tex S 30 Z 60 were used as the weft threads per decimeter. The weft weave rapport is 18. The total strength of warp threads in the fabric is 61,200 N. The breaking load of a strip of MTF-6 fabric with a width of 50 mm is 43600 N. Tensile elongation – 64.5 %. The weight of 1 meter of MTF-6 fabric is 399 cN.

To determine the influence of the structure of multilayer technical fabrics MTF-2 and MTF-6 for power clamps on the conditions of their formation on a loom, four plans of experimental studies were implemented. For series 2 and 4, a second-order orthogonal plan was implemented. Tables 1, 3 give matrices of experimental studies to determine the influence of the initial tension of warp threads PS of protective layers on the magnitude of beating force for the multilayer technical fabric MTF-2 and MTF-6. For series of experiments 1 and 3, the position of the warp guide above the average level and the overstep value φ_Z corresponded to the center of the experiment in series 2 and 4. The joint influence of the overstep and differential tension of the shed on the magnitude of beating force was determined. For the multilayer technical fabric MTF-2, the initial tension of warp threads of protective layers varied from 169.4 cN to 228.2 cN. For the multilayer technical fabric MTF-6, the initial tension of warp threads in protective layers varied from 97.3 cN to 133.0 cN.

Tables 2, 4 give matrices of the second-order orthogonal plan for two factors when determining the joint effect of the use φ_Z and different shed tension *h* on the beating force value for the multilayer technical fabric MTF-2 and MTF-6. An increase or decrease of these parameters leads to a change in the angles of coverage by the main threads of the guides and the conditions of the relative movement of the weft thread in the zone of formation of the multilayer fabrics MTF-2 and MTF-6. For the multi-layer technical fabric MTF-2, the value of overstep varied from 20 to 40 degrees. This overstep's value allows for the normal formation of an outer protective layer for the multilayer technical fabric MTF-2 (Fig. 1, *b*). Different tension of the shed was created with the help of a vertical shift of the upper point of the warp guide relative to the middle position. This value varied from 10 to –10 mm. A minus sign indicates that the warp guide has fallen below the average position. For the multi-layer technical fabric MTF-6, the value of overstep varied from 10 to 20 degrees. This overstep's value allows for the normal formation of an outer protective layer for the multilayer technical fabric MTF-6 (Fig. 2, *b*). Different tension of the shed varied from 10 to –10 mm.

Table 1

Matrix of the plan for determining the influence of the initial tension of warp threads in protective layers on the beating force magnitude for the multilayer technical fabric MTF-2

No.	Warp guide position above average level		Overstep value		Initial tension of warp threads in protective layers
	x_1	*h*, mm	x_2	φ_Z, degrees	P_S, cN
2–1	0	0	0	30	197.1
2–2	0	0	0	30	169.4
2–3	0	0	0	30	183.0
2–4	0	0	0	30	213.0
2–5	0	0	0	30	228.2

Table 2

Second-order orthogonal plan matrix for two factors when determining the joint effect of the application of the overstep and different shed tension on the beating force value for the multilayer technical fabric MTF-2

No.	Warp guide position above average level		Overstep value	
	x_1	*h*, mm	x_2	φ_Z, degrees
2–6	–1	–10	–1	20
2–7	–1	–10	+1	40
2–8	+1	10	–1	20
2–9	+1	10	+1	40
2–10	0	0	–1	20
2–11	0	0	+1	40
2–12	–1	–10	0	30
2–13	+1	10	0	30
2–14	0	0	0	30

Table 3

Matrix of the plan for determining the influence of the initial tension of warp threads in protective layers on the beating force value for the multi-layer technical fabric MTF-6

No.	Warp guide position above average level		Overstep value		Initial tension of warp threads in protective layers
	x_1	*h*, mm	x_2	φ_Z, degrees	P_S, cN
6–1	0	0	0	15	113.4
6–2	0	0	0	15	97.3
6–3	0	0	0	15	110.2
6–4	0	0	0	15	126.1
6–5	0	0	0	15	133.0

Table 4

Matrix of the second-order orthogonal plan for two factors to determine the joint influence of the overstep and the differential tension of the shed on the beating force magnitude for the multilayer technical fabric MTF-6

No.	Warp guide position above average level		Overstep value	
	x_1	*h*, mm	x_2	φ_Z, degrees
6–6	–1	–10	–1	10
6–7	–1	–10	+1	20
6–8	+1	10	–1	10
6–9	+1	10	+1	20
6–10	0	0	–1	10
6 –11	0	0	+1	20
6 –12	–1	–10	0	15
6 –13	+1	10	0	15
6 –14	0	0	0	15

For series 2 and 4, the relationship between named and coded values for the multilayer technical fabric MTF-2 takes the following form:

$$x_1 = \frac{h}{10}, x_2 = \frac{\varphi_Z - 30}{10}. \quad (1)$$

For the multi-layer technical fabric MTF-6, it takes the following form:

$$x_1 = \frac{h}{10}, x_2 = \frac{\varphi_Z - 15}{5}. \quad (2)$$

The experimental setup for determining technological efforts in the formation of the multilayer technical fabrics MTF-2 and MTF-6 is described in detail in [2, 4, 5]. It included an eight-channel amplifier 8ANCh-7M, an oscilloscope N-700, and power supplies for them. Separate measuring strain gauge nodes were intended to determine the tension of warp threads, beating force, the tension of the fabric. Time marks every 0.2 seconds were set directly by the N-700 oscilloscope. For each series, 3 repeated oscillograms were recorded. For each measuring strain gauge node, corresponding calibrated plots were built to determine the tension of warp threads, the beating force, and the tension of the fabric, which were used in the decoding of the oscillograms.

In our work, a series of experimental studies was implemented for the multilayer technical fabric MTF-6. The determination of the influence of the initial tension of warp threads PS in protective layers on the degree of fatigue of warp threads, the weft threads, and the magnitude of destructive load and elongation of the threads pulled from the fabric were studied. For each series, 10 repeated experiments were carried out.

5. Research results on improving the structure of multilayer technical fabric

5. 1. Influence of the initial tension of warp threads on the beating force magnitude for MTF-2 fabric

In accordance with the experimental plan, data were obtained on determining the influence of the initial tension of warp threads in protective layers on the beating force value for the multilayer technical fabric MTF-2 (Table 5). For MTF-2 multi-layer technical fabric, when the filling tension of warp threads in protective layers increases from 169.4 cN (option 2–2) to 228.2 cN (option 2–5), the beating force increases from 144.1 cN to 157.4 cN per one thread. At the same time, there is a decrease in the width of the beating strip from 22.7 mm to 13.0 mm.

The tension of warp at the edge of the fabric at the moment of beating, with an increase in the initial tension, increases for the warp threads in protective layers (PL) from 244.3 cN (option 2–2) to 294.3 cN (option 2–5) and for the warp threads in force layers (FL) from 173.5 cN (option 2–2) to 249.1 cN (option 2–5).

Based on the results of our experiment (Table 5), a regression relationship was constructed to determine the influence of the initial tension of warp threads in protective layers on the beating force magnitude for the multilayer technical fabric MTF-2:

$$P_{SURF2} = 183.86 - 0.58P_{SPL2} + 0.002P_{SPL2}^{2}. \qquad (3)$$

Analysis of regression dependence (3) allows us to state that the beating force magnitude increases with the increase in the initial tension of warp threads in protective layers, which can be explained by the increase in resistance forces during the movement of a weft thread in the formation zone of the multilayer technical fabric MTF-2.

5. 2. Influence of the initial tension of warp threads on the beating force magnitude for MTF-6 fabric

In accordance with the experimental plan, data were obtained on determining the influence of the initial tension of warp threads in protective layers on the beating force value for the multilayer technical fabric MTF-6 (Table 6).

For MTF-6 multi-layer technical fabric, when the tension of warp threads in outer protective layers (PL) increases from 97.3 cN (option 6–2) to 133.0 cN (option 6–5), the beating force increases from 76.7 cN to 90.0 cN per thread. At the same time, the width of the beating strip decreases from 14.6 mm to 12.7 mm. The tension of warp on the edge of fabric at the moment of beating, when the tension of the threads of the warp of outer protective layers (PL) is increased from 150.2 cN (option 6–2) to 208.4 cN (option 6–5) and the threads of the warp of force layers (FL) from 64.1 cN (option II–2) to 93.3 cN (option 6–5), increases as follows: the tension of warp threads in outer protective layers (PL) increases from 150.2 cN (option 6–2) to 208.4 cN (option 6–5), and the tension of warp threads in force layers (FL) increases from 64.1 cN (option II–2) to 93.3 cN (option 6–5).

Table 5

Results of determining the influence of the initial tension of warp threads in protective layers on the beating force magnitude for the multi-layer technical fabric MTF-2

No.	Warp threads	P_S, cN	$P_{BEATING}$, cN		P_{FZ}, cN	P_{RZ}, cN	$t_P \cdot 10^{-2}$, seconds	l_P, mm	P_F, cN
			Statics	Dynamics					
2–1	PL	197.1	66.3	147.5	269.3	254.8	2.60	16.3	74.3
	BIN	52.3			142.0	135.4			
	FL	107.6			218.3	204.5			
2–2	PL	169.4	47.1	144.1	244.3	231.6	3.17	22.7	60.2
	BIN	52.3			137.0	130.4			
	FL	47.1			173.5	102.3			
2–3	PL	183.0	57.5	145.6	258.5	244.2	2.62	17.1	75.0
	BIN	52.2			145.3	137.1			
	FL	74.4			208.4	154.3			
2–4	PL	213.0	72.3	152.7	282.0	267.3	2.43	15.4	97.1
	BIN	52.3			147.4	139.7			
	FL	130.1			236.2	250.6			
2–5	PL	228.2	77.4	157.4	294.3	278.2	2.17	13.0	98.5
	BIN	52.0			144.5	136.0			
	FL	155.7			249.1	292.7			

Table 6

Results of determining the influence of the initial tension of warp threads in protective layers on the beating force magnitude for the multi-layer technical fabric MTF-6

No.	Warp threads	P_S, cN	$P_{BEATING}$, cN		P_{FZ}, cN	P_{RZ}, cN	$t_P \cdot 10^{-2}$, seconds	l_P, mm	P_F, cN
			Statics	Dynamics					
6–1	PL	113.4	43.9	83.9	177.3	165.1	1.80	12.1	52.2
	FL	40.5			72.4	60.8			
6–2	PL	97.3	40.6	76.7	150.2	139.9	2.58	14.6	49.8
	FL	22.1			64.1	52.5			
6–3	PL	110.2	41.5	80.3	163.8	149.5	2.35	13.7	51.0
	FL	29.4			69.1	57.6			
6–4	PL	126.1	49.6	86.9	194.5	180.0	1.65	11.8	58.9
	FL	45.2			80.7	71.4			
6–5	PL	133.0	55.0	90.0	208.4	191.1	1.39	12.7	64.8
	FL	52.4			93.3	82.8			

Based on the results of our experiment (Table 6), a regression dependence was built to determine the effect of the initial tension of warp threads in protective layers on the beating force magnitude for the multilayer technical fabric MTF-6:

$$P_{SURF6} = 48.97 + 0.24P_{SPL6} + 0.001P^2_{SPL6}. \qquad (4)$$

Fig. 3 shows graphical dependences of the influence of the initial tension of warp threads in protective layers on the magnitude of beating force $P_{BEATING}$ for multilayer technical fabrics: 1 – MTF-2; 2 – MTF-6.

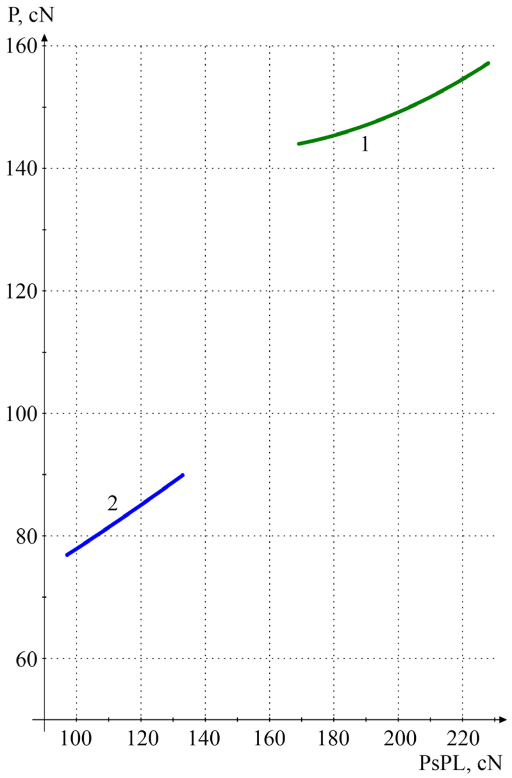


Fig. 3. Graphic dependences of the influence of the initial tension of warp threads in protective layers on the magnitude of beating force $P_{BEATING}$ for multilayer technical fabrics: 1 — MTF-2; 2 — MTF-6

Analysis of graphical dependences in Fig. 3 allows us to assert the increase in the beating force magnitude with the increase in the initial tension of warp threads in protective layers for the multilayer technical fabrics MTF-2 and MTF-6, which can be explained by the increase in resistance forces when moving a weft thread in the fabric forming zone.

5. 3. Combined influence of the overstep and different tension of the shed on the beating force value for the multi-layer technical fabric MTF-2

Two second-order orthogonal plans for actively conducting the experiment were implemented in our work to determine the joint effect of the overstep size φ_Z and the overstep tension h. According to the data in Table 2, for the multi-layer technical fabric MTF-2, the size of the overstep tension varied from −10 mm to 10 mm in steps of 10 mm; the size of the overstep varied from 200 to 400 in steps of 100. According to the data in Table 4, for the multi-layer technical fabric MTF-6, the size of the overstep tension varied from −10 mm to 10 mm in steps of 10 mm; the size of the overstep varied from 100 to 200 in steps of 50.

Using data in Table 7 on the multilayer technical fabric MTF-2 and using the known method for determining the coefficients in the regression equation for the orthogonal plan of the second order, the regression dependences were obtained:

– regression dependence to determine the joint effect of the size of the overstep φ_Z and the differential tension of overstep h on the beating force magnitude (in terms of one warp thread), cN:

$$P_{SURF2} = 177.20 + 1.99h - 2.64\varphi - 0.03h\varphi - 0.02h^2; \qquad (5)$$

– regression dependence to determine the joint effect of the size of overstep φ_Z and the differential tension of shed h on the tension of warp threads in outer protective layers (PL) in front of the warp guide, cN:

$$P_{2PL} = 237.55 + 1.15h - 0.26\varphi - 0.02h\varphi - 0.04h^2; \qquad (6)$$

– regression dependence to determine the joint effect of the size of overstep φ_Z and the differential tension of shed h on the tension of warp threads in force layers (FL) in front of the warp guide, cN:

$$P_{2FL}=176.72+3.54h-0.12\varphi-0.08h\varphi-0.08h^2; \qquad (7)$$

– regression dependence to determine the joint effect of the size of overstep φ_Z and the differential tension of shed h on the tension of warp threads for binding outer protective layers and force layers (BIN) in front of the warp guide, cN:

$$P_{2BIN}=154.15+1.20h+0.74\varphi-0.02h\varphi-0.05h^2. \qquad (8)$$

The adequacy of our regression dependences (3) to (8) was checked using the SPSS software for statistical treatment of experimental data [2, 15, 17]. Analysis of the significance of the coefficients of regression equations (3) to (8) made it possible to reject insignificant ones [2, 15–19]. In regression equations (5) to (8), the size of the overstep φ_Z must be substituted in degrees, and the size h, which characterizes the differential tension of shed, in millimeters.

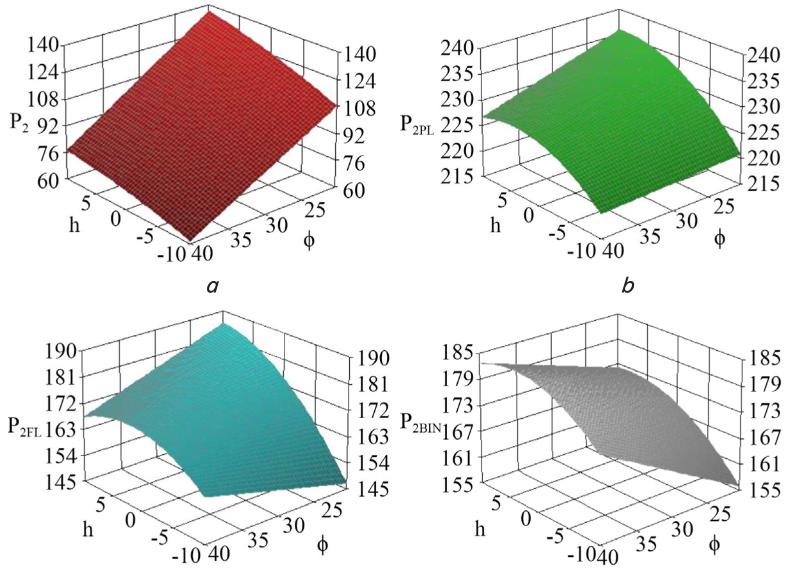
Fig. 4 shows graphical dependences for the multi-layer technical fabric MTF-2 that determine the joint effect of the size of overstep φ_Z and the differential tension of shed h on various values.

Analysis of graphical dependences in Fig. 4 allows us to assert the influence of the size of the overstep and the different tension of the shed for MTF-2 fabric on the growth of the beating force and tension of different systems of main threads. This can be explained by the change in the geometric shape of the shed and the increase in resistance forces during the movement of a weft thread in the area of fabric formation.

Table 7

Results of determining the joint effect of the size of the overstep and the differential tension of the shed on the beating force magnitude for the multi-layer technical fabric MTF-2

No.	Warp threads	$P_{BEATING}$, cN		P_{FZ}, cN	P_{RZ}, cN	P_F, cN
		Statics	Dynamics			
2–9	PL	44.3	122.1	234.1	222.8	72.1
	BIN			158.0	150.2	
	FL			150.6	140.4	
2–7	PL	38.9	103.4	231.0	218.1	81.5
	BIN			153.2	145.8	
	FL			144.1	134.0	
2–8	PL	54.5	144.6	248.2	235.1	69.4
	BIN			171.4	163.9	
	FL			191.1	179.3	
2–6	PL	42.6	113.8	234.2	221.0	80.3
	BIN			158.3	150.2	
	FL			150.4	140.6	
2–12	PL	41.8	107.7	231.2	219.3	74.2
	BIN			155.1	147.5	
	FL			145.0	135.8	
2–13	PL	47.1	125.8	241.3	228.2	78.3
	BIN			169.0	160.1	
	FL			170.4	159.3	
2–10	PL	53.3	138.4	244.7	231.3	72.1
	BIN			169.2	160.1	
	FL			179.4	167.7	
2–11	PL	45.7	116.2	239.2	226.0	76.0
	BIN			164.1	155.5	
	FL			151.3	141.0	
2–14	PL	47.5	124.3	241.3	228.7	71.4
	BIN			168.1	159.6	
	FL			169.0	158.2	



a *b*

c *d*

Fig. 4. Graphical dependences for determining the joint effect of the size of the overstep and the differential tension of the shed for the multi-layer technical fabric MTF-2: *a* – beating force (in terms of one warp thread), cN; *b* – tension of warp threads in outer protective layers (PL), cN; *c* – tension of warp threads in force layers (FL), cN; *d* – tension of warp threads for connecting outer protective and force layers (BIN)

5. 4. Combined effect of the overstep and different tension of the shed on the beating force value for the multi-layer technical fabric MTF-6

Two second-order orthogonal plans for actively conducting the experiment were implemented in our work to determine the joint effect of overstep size φ_Z and the overstep tension h. According to the data in Table 4, for the multi-layer technical fabric MTF-6, the size of shed tension varied from –10 mm to 10 mm in steps of 10 mm; the size of the overstep varied from 100 to 200 with a step of 50. Such a decrease in the size of the overstep, compared to the multilayer technical fabric MTF-2, causes a decrease in the dynamic and static components of the tension of warp threads in protective layers.

Using the data from Table 8 for the multilayer technical fabric MTF-6 and applying the known procedure for determining the coefficients in the regression equation for the orthogonal plan of the second order, the regression dependences were obtained:

– regression dependence to determine the joint effect of the size of overstep φ_Z and the differential tension of shed h on the beating force magnitude (in terms of one warp thread), cN:

$$P_{SURF6} = 96.47 + 0.58h - 1.78\varphi - 0.023h\varphi - 0.003h^2; \quad (9)$$

– regression dependence to determine the joint effect of the size of overstep φ_Z and the differential tension of shed h on the tension of warp threads in outer protective layers (PL) in front of the warp guide, cN:

$$P_{6PL} = 144.03 + 0.83h + 1.36\varphi - 0.08h^2 - 0.14\varphi^2; \quad (10)$$

– regression dependence to determine the joint effect of the size of overstep φ_Z and the differential tension of shed h on the tension of warp threads in force layers (FL) in front of the warp guide, cN:

$$P_{6FL} = 88.30 + 0.32h - 7.56\varphi - 0.01h^2 + 0.22\varphi^2. \quad (11)$$

Table 8

Results of determining the joint effect of the size of overstep and the differential tension of shed on the beating force magnitude for the multi-layer technical fabric MTF-6

No.	Warp threads	$P_{BEATING}$, cN		P_{FZ}, cN	P_{RZ}, cN	P_F, cN
		Statics	Dynamics			
6–9	PL	37.3	72.1	114.3	105.4	35.1
	FL			41.6	32.2	
6–7	PL	37.6	70.0	107.5	98.9	28.4
	FL			33.8	25.4	
6–8	PL	43.1	84.2	150.4	141.6	44.3
	FL			47.1	36.2	
6–6	PL	37.9	77.5	140.1	129.5	34.6
	FL			37.7	29.9	
6–12	PL	36.9	73.8	137.3	126.6	30.3
	FL			32.5	21.3	
6–13	PL	39.8	79.7	143.0	133.5	37.2
	FL			38.9	30.0	
6–10	PL	40.1	82.5	155.2	144.5	36.9
	FL			49.7	40.6	
6–11	PL	36.9	73.4	138.2	127.1	29.4
	FL			31.7	22.4	
6–14	PL	36.8	75.3	140.2	129.1	36.2
	FL			33.8	24.8	

The adequacy of our regression dependences (9) to (11) was checked using the SPSS software for statistical treatment of experimental data. Analysis of the significance of the coefficients of regression equations (9) to (11) made it possible to discard the insignificant ones. In regression equations (9) to (11), the size of overstep φ_Z must be substituted in degrees, and the size *h*, which characterizes the differential tension of shed, in millimeters.

Fig. 5 shows graphical dependences for the multi-layer technical fabric MTF-6 that determine the joint effect of the size of overstep φ_Z and the differential tension of shed *h* on various values.

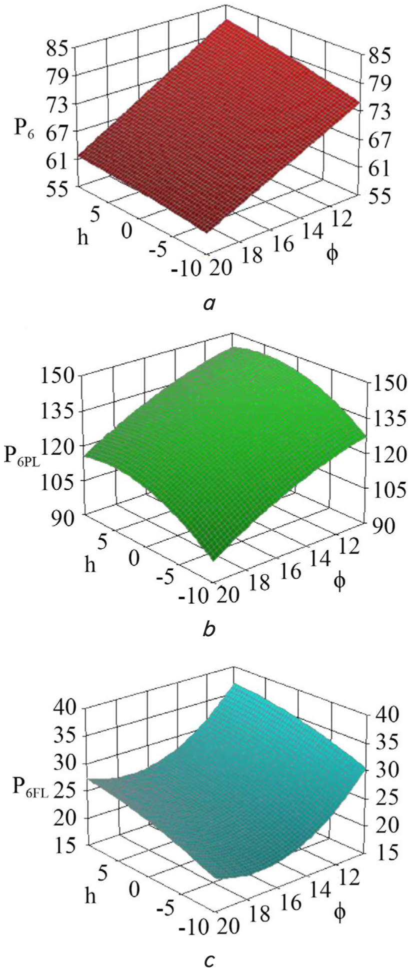


Fig. 5. Graphical dependences for determining the joint effect of the size of the overstep and the differential tension of the shed for the multi-layer technical fabric MTF-6: *a* – beating force (in terms of one warp thread), cN; *b* – tension of warp threads in outer protective layers (PL), cN; *c* – tension of warp threads in force layers (FL), cN

In our work, a series of experimental studies for the multi-layer technical fabric MTF-6 was carried out. The goal was to determine the influence of the initial tension of warp threads PS in protective layers on the amount of deformation of warp threads, weft threads, as well as on the breaking load and elongation of threads removed from the fabric. Table 9 gives the results of determining the joint effect of the size of the overstep and the differential tension of the shed on the beating force magnitude for the multilayer technical fabric MTF-6.

Fig. 6 shows a comparative analysis of the conditions for manufacturing the multilayer technical fabrics MTF-2 and MTF-6. This diagram is built using the data in Tables 5–8 and regression dependences (5) to (11).

Table 9

Results of determining the joint effect of the size of the overstep and the differential tension of the shed on the beating force magnitude for the multi-layer technical fabric MTF-6

No.	Warp threads	Strain %	Breaking load [N]	Breaking elongation %
6–1	PL	10.8	91	22.3
	FL	4.9	163	23.2
6–2	PL	12.7	94.3	22.5
	FL	4.7	166	23.4
6–3	PL	12.6	93	22.6
	FL	4.7	164	23.1
6–4	PL	9.5	90	22.4
	FL	5.0	162	23.2
6–5	PL	9.2	90	22.3
	FL	5.1	160	23.2

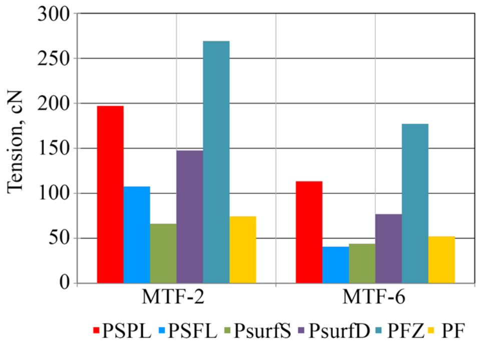


Fig. 6. Comparative analysis of manufacturing conditions for the multilayer technical fabrics MTF-2 and MTF-6: 🟥 – tension of warp threads in outer protective layers (PL) under static conditions P_{SPL}; 🟦 – tension of warp threads in force layers (FL) under static conditions P_{SFL}; 🟩 – beating force calculated per one warp thread under static conditions $P_{BEATING}S$; 🟪 – beating force calculated per one warp thread under static conditions of dynamics $P_{BEATING}D$; ■ – tension of warp threads in outer protective layers (PL) in front of the formation zone fabric P_{FZ}; 🟨 – fabric tension in terms of one warp thread P_F

A comparative analysis of conditions for the production of multilayer technical fabrics (Fig. 6) made it possible to establish that the technological loads during the production of the multilayer technical fabric MTF-6 are, on average, 30–100 cN less than those of the multilayer technical fabric MTF-2. Our results could be used to improve the structure and manufacturing technology of multilayer technical fabrics.

6. Discussion of results of the study on determining the rational structure of multilayer technical fabric for power clamps

Based on the results of our experiment (Table 5), a regression dependence was built to determine the effect of the initial tension of warp threads in protective layers on the beating force magnitude for the multilayer technical fabric MTF-2 (3). Analysis of regression dependence (3) allows us to state that the beating force magnitude increases with the increase in the initial tension of warp threads in protective layers. This can be explained by the increase in resistance forces during the movement of the weft thread in the zone of MTF-2 fabric formation. Based on the results of our experiment (Table 6), a regression dependence was constructed to determine the influence of the initial tension of warp threads in protective layers on the beating force magnitude for the multilayer technical fabric MTF-6 (4). Using the data in Table 7 for MTF-2 fabrics and using a known procedure for determining the coefficients in regression equation for the second-order orthogonal plan, regression dependences (5) to (8) were obtained. These dependences determine the joint effect of the size of overstep φ_Z and the differential tension of shed h on the magnitude of the beating force, on the tension of warp threads in outer protective layers. Also, dependences (5) to (8) determine the influence of the size of overstep φ_Z and the differential tension of shed h on the tension of warp threads in force layers, on the tension of warp threads for binding the outer protective layers and force layers. Using the data from Table 8 for MTF-6 fabrics, regression dependences (9) to (11) were obtained to determine a beating force value, the tension of warp threads in outer protective layers, the tension of warp threads in force layers.

A special feature of our study is to determine the rational structure of multilayer technical fabric for power clamps, which makes it possible to obtain the effect of minimizing the consumption of raw materials and reducing energy costs for manufacturing a unit of products. Experimental studies made it possible to build regression dependences for determining the influence of the initial tension of warp threads in outer protective layers on the beating force value. The joint effect of the size of the overstep and the different tension of the shed on the beating force value, depending on the structure of the multilayer technical fabric, was established. It is shown that when the tension of warp threads in outer protective layers increases, the beating force value increases. This can be explained by the fact that friction forces increase in the zone of multilayer fabric formation between the main threads and the weft threads.

For the MTF-6 fabric (width 20 cm), 744 polyamide complex threads 29 Tex of high twist S110x2 S300 Z 180 were used as warp threads in outer protective layers (PL). 744 polyamide complex threads 93.5 Tex S were used as warp threads in force layers (FL) 30 Z 60. 100 polyamide complex threads 93.5 Tex S 30 Z 60 were used as weft threads per decimeter. The weft weave rapport is 18. The total strength of the warp threads in the fabric is 61,200 N. The breaking load of a strip of MTF-6 fabric with a width of 50 mm is 43600 N. Tensile elongation – 64.5 %. The weight of 1 meter of MTF-6 fabric is 399 cN.

We determined the joint influence of the overstep and the differential tension of the shed on the beating force value. For the multilayer technical fabric MTF-2, the initial tension of warp threads in protective layers varied from 169.4 cN to 228.2 cN. For the multilayer technical fabric MTF-6, the initial tension of warp threads in protective layers varied from 97.3 cN to 133.0 cN.

A comparative analysis of production conditions of the multilayer technical fabrics MTF-2 and MTF-6 made it possible to establish that the tension of warp threads in outer protective layers (PL) under static conditions decreased by 43 % (from 197.1 cN to 113.4 cN). The tension of warp threads in force layers (FL) under static conditions decreased by 62 % (from 107.6 cN to 40.5 cN). Beating force calculated per warp thread in statics decreased by 33 % (from 66.3 cN to 43.9 cN).

The beating force, calculated per one warp thread in dynamics, decreased by 48 % (from 147.5 cN to 76.7 cN). The tension of warp threads in outer protective layers (PL) in front of the fabric forming zone decreased by 35 % (from 269.3 cN to 177.3 cN). Fabric tension, calculated per a warp thread, decreased by 30 % (from 74.3 cN to 52.2 cN).

The size of the beating strip decreased from 22.7 mm to 14.1 mm. This indicates that the multi-layer technical fabric MTF-6 is produced on the machine under lower technological loads. This makes it possible to significantly reduce the percentage of thread breakage, preserve its strength characteristics, and increase the productivity of technological equipment.

Using the multi-layer technical fabric MTF-6 makes it possible to ensure the entire set of physical, mechanical, and consumer properties and obtain an effect when introduced into production through the minimization of raw material costs and reduction of energy costs for the production of a unit of products.

The features of the proposed structure of the multilayer technical fabric for MTF-6 power clamps are that the connection between the separating layer and the two protective layers is carried out using the main threads in protective layers. This distinguishes this structure from the prototype, the multi-layered technical fabric for power clamps MTF-2, in which this connection is carried out by means of an additional third system of main threads. This complicates the system of filling the main threads of the machine due to the introduction of the third thread. In this way, the problem of determining the rational structure of multilayer technical fabric for power clamps is solved, which makes it possible to obtain an effect when introduced into production through the minimization of raw material costs and the reduction of energy costs for manufacturing a unit of products.

Limitations in our work relate to the filling tension of main threads. A decrease in the filling tension led to sagging of the warp threads in the zone of formation of multilayer technical fabric, and an increase in the filling tension led to massive breaks. For the multilayer technical fabric MTF-2, the initial tension of warp threads in protective layers varied from 169.4 cN to 228.2 cN. For the multilayer technical fabric MTF-6, the initial tension of warp threads in protective layers varied from 97.3 cN to 133.0 cN. This also applies to the magnitude of the overstep and the vertical shift of the upper point of the warp guide relative to the average position. For the multi-layer technical fabric MTF-2, the amount of overstep varied from 20 to 40 degrees. Different tension of the shed was created with the help of a vertical shift of the upper point of the warp guide relative to the middle position. This value varied from 10 to –10 mm. A minus sign indicates that the warp guide has fallen below the average position. For the multi-layer technical fabric MTF-6, the amount of overstep varied from 10 to 20 degrees.

The disadvantages of the proposed structure of the multilayer technical fabric for power clamps MTF-6 include a decrease in the surface density of protective layers due to the presence of threads in the areas of the connection of the separate layer with protective layers. This decrease leads to an increase in the specific pressure in the contact zone of the power clamp with the surface of pipe insulation.

The development of this study involves further improvement of the spatial structural scheme of a multilayer technical fabric. This refers to the technique of connecting layers, choosing the structure of force layers.

7. Conclusions

1. For the multilayer technical fabric MTF-2, warp tension at the edge of the fabric at the moment of beating, with an increase in the initial tension, increases for warp threads in protective layers (PL) from 244.3 cN (option 2–2) to 294.3 cN (option 2–5) and for warp threads in force layers (FL) from 173.5 cN (option 2–2) to 249.1 cN (option 2–5).

2. For the multilayer technical fabric MTF-6, tension of the warp on the edge of the fabric at the moment of beating with an increase in the tension of warp threads in outer protective layers (PL) is from 150.2 cN (option 6–2) to 208.4 cN (option 6–5) and the warp threads in force layers (FL) from 64.1 cN (option II–2) to 93.3 cN (option 6–5).

3. For the multilayer technical fabric MTF-2, we established the joint effect of the size of the overstep and the different tension of the shed on the beating force value, depending on the structure of multilayer technical fabric. The tension of warp threads in outer protective layers (PL) under static conditions decreased by 43 %. The tension of warp threads in force layers (FL) under static conditions decreased by 62 %. Beating force, calculated per one warp thread in statics, decreased by 33 %.

4. For the multilayer technical fabric MTF-6, we established the joint effect of the size of the overstep and the difference in tension of the shed on the beating force value, depending on the structure of multilayer technical fabric. Beating force value, calculated per one warp thread in dynamics, decreased by 48 %. The tension of warp threads in outer protective layers (PL) in front of the fabric forming zone decreased by 35 %. The fabric tension, calculated per warp thread, decreased by 30 %. The size of the beating strip decreased from 22.7 mm to 14.1 mm. Regression dependences of the beating force magnitude on the value of overstep and the different tension of shed were built.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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