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TECHNOLOGY OF SHAPE FORMATION IN VOLUME AREAS OF SEWING PRODUCTS PARTS USING A VACUUM INSTALLATION TO FORM A CLOSED TECHNOLOGICAL SPACE

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Abstract. *This article provides a detailed analysis of the processes of wet heat treatment in the manufacture of the upper range, describes the principle of operation of a special vacuum forming device and detailed characteristics of various degrees of vacuum. as well as the theoretical foundations of the aerodynamic passage of air in a vacuum mode during shaping and the results of studies of several types of suit fabric for breaking load, the corresponding results correspond to the above studies. The substantiation of the sizes of perforations is carried out depending on the limiting state of the deformable tissue, characterized by the breaking load.*

Keywords: *vacuum space, molding, aerodynamics, bursting load, perforation, air flow, deformation, low-operation technology, shell.*

An important direction for improving the technology of making garments is to improve their quality by forming and stable fixation of the given configuration of clothing parts. In general, the quality of clothing largely depends on the shape of the main parts and its preservation during the operation of the product. Modern technology, called "fabrication of garments by molding method" [1], is aimed at creating complex given shape of the garment with a minimum number of seams. Thus, direction has been formed, related to manufacturing clothes on the basis of low-operational technology, when given shape is obtained by changing the angle between warp and weft threads without deformation of fabric thread length (theory of "Chebyshev's net").

Textile materials are pressed by applying pressure to create a given shape of clothing parts from fabrics or packages, technological steam and temperature for a certain period of time. However, there is deterioration of its physical and mechanical properties and a decrease in the quality of the garment as a result of mechanical impact on the processed semi-finished product.

In the process of shaping and use of pressing pressure, the threads of the material or package of semi-finished products are subjected to undesirable forces and microscoFig fractures of fibers, which reduces the mechanical characteristics (breaking load, breaking elongation). WHT (wet heat treatment) operations also lead to deterioration of hygienic (air permeability, vapor permeability) indicators, which was confirmed in our studies [2]. Thus, the results of experimental studies of physical-mechanical properties of packages after WHT show that their properties are lost by an average of 15-21 %.

Based on the above, it follows that in order to improve processing quality by preserving physical, mechanical and hygienic properties of textile materials, it is necessary to improve the method of shaping, which excludes the appearance of damage and negative effects on the package of garment parts from the working bodies (matrix and punch) of the equipment for WHT. The disadvantage of these devices is that the shape of the punch and matrix is constant.

The most perfect for molding volumetric clothing parts is a special device [3], representing a perforated mold-cradle, made in the form of upper and lower cushions. The upper cushion has nozzles for supplying polymer composite material and hot air (t=125-130 ^{0}C), designed for reliable fixation of the created shape of the garment parts. The perforation is performed in the lower cushion, connected to the vacuum unit (Fig.1). The lower cushion 1 is made with perforations 2, through which the air is sucked from the air chamber 3 (closed technological space) by vacuum unit and through the pipeline 5. For shaping, for example, the back of a men's jacket fabric 6 is placed on the bottom cushion 1 and at the expense of vacuumization of the closed technological space created by the profile of the bottom cushion, deformation of the fabric occurs.

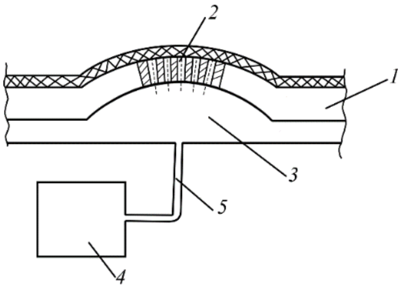

Fig.1. The lower cushion of the vacuum forming device for clothing parts:
1-pillow, 2-perforation, 3-air chamber,
4-vacuum unit, 5-pipe.

Deformation of the fabric is carried out in tight contact with the outer surface of the bottom cushion, created by a stream of suction air through the perforations with a vacuum unit. Thus, the deformed tissue copies the shape of the lower cushion. The upper cushion [4] is used for fixation of the obtained form, in which special nozzles for feeding of polymer composite material are installed, and a device (calorifer) is also provided for simultaneous feeding of hot air in order to intensify the process of form fixation and drying. Vacumization of the closed technological space under the bottom cushion consists in rarefying the air (gas) and bringing it to a state at a pressure below atmospheric. Depending on this ratio, one distinguishes between degrees of ultrahigh (λ≫r), high (λ> *r),* medium (λ*r*) and low (λ≪r) vacuum [4].

The average free path length of molecule, taking into account the relative velocity distribution of the colliding molecules, is equal:

$$\overline{\lambda} = \frac{1}{\sqrt{2} n_o \delta}, \qquad (1)$$

where $_{no}$ is the number of molecules in cm3 of gas; δ is the effective impact cross section.

In the case of the collision of molecules having a diameter *d≈10-8cm*, the effective gas-kinetic cross section is equal to the area of the circle with a radius *d* (the effective diameter of the molecule):

$$\delta = \pi d^2 \qquad (2)$$

To evaluate the performance of vacuum system, it is useful to know some characteristics of the different vacuum degrees (Table 1.)

Table 1
Characteristics of the different vacuum grades

Features	Vacuum			
	low	Medium	high	super high
Pressures characteristic of given degree of vacuum, mmHg.	760-1	1-10-3	10-3-10-7	10-8 or less
Number of molecules, m3	1025-1022	1022-1019	1019-1013	1013 or less

Dependence on pressure of the coefficients of thermal conductivity and internal friction	Pressure-independent	The dependence on elongation is determined by the parameter *d*	Directly pro-portional to the pressure	Both phenomena are virtually non-existent

To determine the degree of vacuum during shaping of garment elements, it is necessary to calculate the average run length   of air molecules (1) and compare it with the dimensions of garment parts corresponding to the closed technological space within the volume of the lower cushion (Fig. 1). Thus, for example, for an average vacuum, when the number of molecules per m3 is $n_o=10^{22}$-10^{19} (Table 1), the average run length   is *0.0225-2.25* m. This range of path lengths is quite comparable with linear dimensions (r) of the device for vacuuming with the purpose of shaping the garment elements, i.e. for the average vacuum $\lambda \leq r$. [5] Many perforations within the working area of the lower cushion of this device are provided for shaping garment parts by means of vacuuming. The perforations can have different configurations (Fig.1). The choice of the perforation shape depends on peculiarities of aerodynamics of air passage and creation of favorable conditions of deformation of the fabric located on the working surface of the cushion. Thus, for vacuumization of the closed technological space formed by the lower cushion circuit, the pressure corresponding to the average degree of vacuum is p=1-10-3 mm Hg. (1 mm Hg =133.322 Pa). Vacuumization is carried out by means of pumping (suction) of air from some closed hermetic space by means of vacuum pump. In the present device (Fig.1) air jets pass through holes of various forms (Fig.2): conically tapering (Fig.2,a) to lower surface (confuser); conically expanding (Fig.2,b) to lower surface (diffuser); cylindrical (Fig.2,c). Consideration of passing of air stream or any other gas through perforations in order to perform aerodynamic calculation is based on the main provisions and laws of hydrodynamics. However, while the physical properties of droplet liquids in their motion remain constant and do not contract or expand as pressure and temperature change, the physical properties of gases are functionally dependent on temperature and pressure. Gases are characterized by high velocities and are capable of expanding and contracting over a wide range. The movements of gases are associated with internal thermodynamic processes (mutual transformation of thermal energy into mechanical energy).

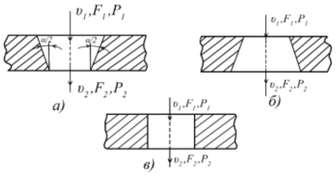

Fig. 2. Types of perforations and aerodynamic characteristics (-speed of air flow; F-sectional area of the hole; p-pressure):

(a) perforation as confusor (*P1>P2; F1> F2; V1> V2)*

b) perforation as diffuser (*P1<P2; F1<F2; V1<V2)*

c) perforation in the form of cylindrical hole (*P1=P2; F1=F2; V1=V2*)

The basic equation of hydrodynamics is D. Bernoulli's equation, which expresses the law of conservation of mechanical energy in the motion of an ideal fluid, which has no viscosity and have absolute mobility. In the case of a real fluid that has viscosity, there are forces of resistance to fluid motion - internal and external friction. Therefore, some of the pressure energy is expended irretrievably. These losses are characterized as friction head loss or linear head loss $h_{тр}$.

In addition to friction head losses, there are also local resistance head losses $h_{тр}$., which are caused by geometric, structural and technological features of moving (transporting) the fluid (gas) flow. Therefore, total losses of real liquid at any section of the pipeline $h_{пот}$ are equal:

$$h_{пот} = h_{тр} + h_м \tag{3}$$

In the general case, local resistance, causing energy losses during the movement of fluid (gas), is determined by a number of factors: 1) changes in the cross section (expansion or contraction); 2) curvature and curvature of the duct (flow rotation); 3) branching or merging of flows; 4) combination of the above factors in various devices.

Important in aerodynamic calculations is the consideration of local resistance on the design basis, when there is a sudden and smooth expansion and contraction of the pipeline in places where its cross section changes. The head losses (in meters) for local resistances are determined by the Weisbach formula [6]:

$$h_м = \zeta(v^2/2g) = \zeta h_v, \tag{4}$$

where $h_v = v^2/2g$ – - velocity head;

or by expressing through the pressure loss $\Delta P_т(кгс/м^2)$ in the local resistance:

$$\Delta p_м = (\gamma v^2/2g), \tag{5}$$

where ζ – - dimensionless coefficient (local resistance coefficient), which expresses the head loss in fractions of the velocity head and is determined experimentally.

When the duct is suddenly constricted, the airflow is first compressed and then expands. The head loss during sudden contraction occurs mainly in the expansion section. These losses depend on the velocities of the gas (liquid) in the compressed flow section $V_{сж}$ and in the narrow section of the pipe V_2..

The head loss at sudden contraction is determined by the Bord formula, which is derived from D. Bernoulli's equations and momentum of forces:

$$h_м = [(1/\varepsilon - 1)]^2(v_2^2/2g) = \zeta(v_2^2/2g) \tag{6}$$

where $\zeta = \left(\frac{1}{\varepsilon} - 1\right)^2$ – - is the coefficient of local resistance referred to the velocity in the narrow cross-section of the pipeline; $\varepsilon = F_{сж}/F_2$ – - compression coefficient, defined as the ratio of the area of the compressed flow section $F_{сж}$ to the pipe area in the narrow section $F2$.

The compression coefficient can be determined by the approximate formula of A.D. Altschul:

$$\varepsilon = 0{,}57 + [0{,}043/(1{,}1 - n)], \tag{7}$$

where $n = F_2/F_1$ – - is the ratio of the areas of the pipe in the narrow and wide sections.

Table 2 shows the values of ζ depending on the ratio of areas n in the narrow F2 and wide F1 sections of the pipe [7].

Table 2

The values of the local resistance coefficient ζ depending on n

n=F2/F1	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	1
ζ	0,41	0,4	0,38	0,36	0,34	0,3	0,23	0,2	0,16	0

Sharp reduction of head loss during flow compression occurs during smooth contraction of the pipeline, called confusor (Fig. 2a). In the confuser there is almost no separation of jets from the main flow and therefore there is a smooth contraction of the liquid (gas). The values of local resistance coefficient ζ for the confusor, which is included in formula (6), are determined taking into account the correction factor $k_{сж}$::

$$\varepsilon_{\text{конф}} = k_{сж}\zeta = k_{\text{сж}}\left(\frac{1}{\varepsilon} - 1\right)^2 \tag{8}$$

Due to the increase of velocity in the confusor, part of the pressure energy is converted into kinetic energy. Sudden expansion of the flow occurs in places where the cross-section of the pipeline changes from smaller to larger. The head loss during sudden expansion is also determined by the Bord formula (4):

$$h_{\text{м}} = \zeta(v_1^2/2g), \tag{9}$$

where ; $\zeta = (1 - V_2/V_1)^2$; $v_1^2/2g$ – - is the velocity head in the narrow section of the pipeline.

Since velocities *V1* and *V2 are* inversely proportional to the cross-sectional areas of the pipeline, we can express as follows:

$$\zeta = \left(1 - \frac{F_1}{F_2}\right)^2 = \left[1 - \left(\frac{d_1}{d_2}\right)^2\right] \tag{10}$$

If we relate the coefficient of local resistance to the velocity head in the wide section, we get an inverse relationship:

$$h_{\text{м}} = \left(\frac{V_1}{V_2} - 1\right)^2 (v_2^2/2g) = \left(\frac{F_2}{F_1} - 1\right)^2 (v_2^2/2g), \tag{11}$$

When making a smooth transition from a smaller to a larger cross-section of the pipeline (Fig. 2, b), called a diffuser, the head loss is drastically reduced. The head loss in the diffuser consists of friction losses along its length and losses caused by energy consumption for flow expansion. The head loss depends on the opening α angle . As the opening angle decreases α the swirl and the detachment of the jets become smaller, and therefore the energy loss is also smaller [6].

In the diffuser, in contrast to the confuser, there is a conversion of part of the kinetic energy into pressure energy. Taking into account $k_{\text{см}}$ the pressure loss for local resistance in the diffuser is determined by the general formula of local resistance coefficient:

$$h_{\text{м}} = k_{см}[(v_1 - v_2)^2/2g] \tag{12}$$

Analyzing aerodynamics of air passing through different configuration of perforations, we can conclude that a smooth transition from the inlet cross-section to the outlet cross-sections by the shape of the confuser made in the lower cushion of the shaping device is preferable. This is due to the fact that during vacuumization of technological space air suction (suction) occurs from a larger cross-section (upper perforation plane) to a smaller cross-section (lower perforation plane). From Bernoulli's equation and the continuity equation: (($Q = V_1 \cdot F_1 = V_2 \cdot F_2 = const$,, Q-volume flow rate) it follows that when liquid (gas) flows in horizontal pipe having different cross-sections, liquid velocity is higher in places of contraction, and pressure is higher in wider places, i.e. where velocities are lower.

Since air appears to be a compressible fluid, D. Bernoulli's equation for liquid product flow is quite applicable to any gas flow at small pressure drops. Thus, in a particular case, when the temperature difference between the transported air and the environment is small, we can neglect the difference in geometric pressures and D. Bernoulli's equation has the form [10]:

$$\frac{P_1}{\gamma}+\frac{V_1^2}{2g}=\frac{P_2}{\gamma}+\frac{V_2^2}{2g}=const, \text{м} \tag{13}$$

or, let us present it in a form more convenient for aerodynamic calculations:

$$p_1+\frac{\gamma V_1^2}{2g}=p_2+\frac{\gamma v_2^2}{2g}=const, \text{кгс/м}^2 \tag{14}$$

where *p1, v1* - pressure and gas velocity in the inlet section of the pipeline respectively; *p2, v2* - pressure and gas velocity in the outlet section of the pipeline respectively;

γ - volume weight (density) of gas, kg/m3. In aerodynamic calculations for standard air volume weight γ = 1.2 kgf/m3 should be assumed.

For any pipeline section the friction loss ($\Delta p = \Delta p_{тр}$) along the length *l can be* determined for circular sections by the Darcy formula:

$$\Delta p_{тр}=\frac{\lambda}{d}\cdot\frac{\gamma V^2}{2}\cdot l, \text{Па} \tag{15}$$

where λ is the coefficient of friction loss along the length *l*; *d* is the duct diameter, m;

For approximate calculations, λ can be assumed to be 0.02.

It follows from formula (7) that the friction loss is directly proportional to the length (in our case, the thickness of the bottom cushion) of the duct and inversely proportional to the diameter of the hole. The head loss Δp increases as a parabolic function of the air velocity.

Ducts are usually made of thin sheet steel, for which the absolute roughness is taken equal to *k=0.1* mm. When making ducts from other constructional materials, it is necessary to add a correction factor β to the tabulated values of friction resistance $k_{тр}$ and λ/d which takes into account the change in $h_{тр}$ and is determined by the formula:

$$\beta=(kV)^{0,25}, \tag{16}$$

where *k* - absolute roughness of the duct wall, mm; *V* - air velocity, m/s.

Thus, in the manufacture of perforations in the form of a confusor, the diameter of the outlet hole can be taken equal to 2 mm and the diameter of the upper hole - 4 mm based on technological considerations. To determine the total number of perforations arranged in the form of an elementary cell (Fig. 3), it is necessary to correlate the dimensions of the shaping surface of the garment element and the pitch of the holes (t). In this case, we will take constructively a step equal to 6 mm, which allows to locate in the center of the cell an additional hole d2=2mm.

Let us make an approximate calculation of the loss of suction air head through the perforations with the help of the described installation, taking into account geometrical parameters of the holes in the bottom cushion and mechanical characteristics of the deformed fabric. For the numerical example, we will take the following values of the diameters of the confuser holes: 4 and 2 mm. With these data, the taper angle α is ~20°. In case of sudden contraction, the head loss is determined by formula (6), where to calculate the head loss, it is necessary to first find the local resistance coefficient ζ and the compression coefficient ε. The compression coefficient is determined by formula (7), where *n=F2/F1* is the ratio of the areas of holes in the narrow and wide sections:

F1=12.56 mm2; F2=3.14 mm2 $\varepsilon=0{,}57+[0{,}043/(1{,}1-3{,}14/12{,}56)]=0{,}62$

$$\zeta=\left(\frac{1}{\varepsilon}-1\right)^2=\left(\frac{1}{0{,}62}-1\right)^2=0{,}376$$

With a known value of the air flow rate in the narrow section, the head loss can be calculated (6).

Thus, for practical implementation of this method of shaping clothing elements, it is necessary to perform perforations in the form of a confusor in the lower cushion of the device in question. Perforations in the form of a confusor in accordance with the basics of aerodynamics provides a tighter fit of the deformed fabric to the surface of the cushion due to increasing the areas covered by the pressure of sucked air during vacuumization and greater pressure in the upper plane of the cushion due to the increased size of the hole compared to the outlet holes. The justification of perforation sizes depending on the limiting condition of the deformed fabric, characterized by the breaking load, is performed. It is shown that, taking into account the size of clothing elements, to form them it is necessary to create an average degree of vacuum, determined by the pressure of 1-10-3mm Hg.

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