DEVELOPMENT OF INNOVATIVE TECHNOLOGIES FOR DESIGN-FORMATION OF WOMEN'S HATS FROM FABRIC IN LAWE

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Abstract: *The article is devoted to the development of innovative technologies of design-forming of women's hats from fabrics in a special working environment. It is suggested to use water as a working environment, which creates a different forming effort. Seven original methods of hydroforming with the use of LAWE have been developed to ensure the quality design-formation of the three-dimensional parts of women's fabric hats. To test and implement the developed methods, appropriate experimental equipment is designed and features of its work are given. Based on the experimental studies, it is determined the optimal parameters for forming volumetric details of women's hats for each method. Examples of formed hats on the specified equipment are given. The prospects of further researches for work improvement of the developed equipment are offered.*

Keywords: *LAWE, women's hats, formation of the details from the fabric, methods of formation, pressure of LAWE, forming element, forming chamber.*

1 INTRODUCTION

Today, a significant stylistic disadvantage of suit forming is imbalance of consumer ensemble. The noted problem is arising as a result of limited set of basic artistic techniques for harmonizing the image. A significant role in visualizing of the idea of a costume is played by layout of the form, color and texture of its constituent elements [1, 2]. A main goal in this case is integrity of perception of created artistic and aesthetic image, which cannot be achieved without a harmonious combination of materials.

In the manufacture of outerwear, fabrics are in great demand, unlike more expensive leather, fur and materials with a film coating. Headset completion can be either embroidered or formed headgear made from fabric [3].

Light industry market fully meets the demand of consumers for hats made from fur, leather and felt. Also hats are sewn from fabrics, which are formed in a constructive way [4]. But for manufacture of these products, multi-operational and energy-intensive technologies are used. At the same time, there are no models of formed headwear, made from fabrics that are often the reason for headdress not to match the style, color and texture of the coat, dress and suit. The development of a new technology for forming parts of hats from fabrics needs a unique scientific method, which is based on an integrated approach to the system of technological preparation of production and design of highly productive equipment [5].

The processes of form creation and the form fixing of clothing parts made from polymer materials are largely determined by deformation-relaxation processes that occur in material under influence of various external factors, including mechanical load. The required strain can be achieved by extension, compression, bending and shear [6, 7]. The most difficult in the technology of clothing parts forming is a method of obtaining a three-dimensional shape, which approaches the surface of spherical segment. The complexity is primarily due to anisotropy of fabrics properties, which manifests in unequal directions of material along the warp, weft and at an angle to them during deformation. In this case, a surface form obtained by a mechanical method is different from segment of forming spherical organ [8]. Thus, the final shape of a part, obtained in the forming process, can be different from the shape of forming organ. The forming methods (planar or volumetric), magnitude and direction of deformation forces, nature of deformation have a great influence on the deformation mechanism in most of fabrics with "rough" structure.

A number of scientists [5-7] studied deformation properties of fabrics under the action of a flexible membrane and pressed on a hemispherical surface. The authors of [5-7] found that giving deformations to a textile material on a volumetric form is more difficult process, than on a plane one. In addition, deformation of the fabric on volumetric form will be different in the upper part of hemisphere and on its edges. That is, deformation is uneven over the entire area. As a result of research it was found, that upon action on the fabric of deformation in form of a load of pulsating character, which is formed by compressed air on the surface of hemisphere, there is a uniform deformation of the fabric (textile material) in two directions: warp and weft. That is, it can be argued that this type of load allows providing maximum activity of "rough" and "thin" structure of the fabric.

Based on this, it is possible to put forward the hypothesis that wet heat treatment (WHT), in its classical form, is advisable to modify to achieve the goals of forming hats. As the main factors of WHT process are moisture, mechanical force and temperature, when applying dynamic methods, the last factor, namely temperature, can be eliminated, which will also significantly reduce energy consumption of the process.

Design of forming parts of clothes can be carried out in a static, dynamic and centrifugal field using different equipment [9, 10]. Some forming methods take into account the protective properties of the materials [11]. In accordance with this, there are traditional and non-traditional methods of forming parts of clothes. Traditional forming methods include those, which are characterized by the action of static loads: use of irons, presses and steam-air mannequins.

The most common way of forming parts of hats under static loads is by pressing on press-forms [1, 4, 8]. The design consists of two parts, one of which is movable (punch), and the other is stationary (matrix). When press-form is closed, a gap between die and punch determines a final quality of formed product. Discrepancies between punch and die, and low activity of "rough" structure of material are disadvantages of this forming method.

The Widespread WHT for clothes also uses a variety of irons and presses. The pressure on semi-finished product, which is processed, is provided by a weight of iron and performer's effort. When using this method, it is difficult to withstand necessary processing modes and obtain necessary level of quality of forming operations. From the above, it can be concluded that the use of traditional methods in clothes forming has certain disadvantages [4, 5, 8]:

- providing unequal pressure on textile materials with surfaces of press pillows and soles of irons;
- difficulty in reconstruction of the form conformity;
- combination of upper and lower press pillows;
- application of significant mechanical load on a fabric due to the action of press pillows or iron mass;
- the use of the same type of press pillows of different full-size groups for forming parts of clothes;
- las formation on the surface of material;
- lack of activity of the "rough" structure of textile materials and, as a result, a slight change in network of angles.

Taking into account the given disadvantages of traditional methods, it is appropriate to search for innovative methods of forming three-dimensional parts of clothes from textile materials in the field of dynamic forces, which to some extent departs from the classical WHT.

There are some works in the field of forming which take into account maximum of textile materials properties, including deformation. Their purpose is to provide accurately a designed headgear form and disadvantages of classic forming methods.

In this case, deformation of polymeric material can be performed in different working environments, when using different forming forces, in different planes, with different placement of forming element to the direction of deformation force.

Hydro-jet technology of forming details of women's hats made of textile materials is widely used today [12-14]. It is based on the action of a water jet on textile material under high pressure [15]. Due to the use of a special nozzle, considerable effort can be made in forming parts of various shapes [16]. The advantage of this technology is the ability to form parts of various shapes and layered of the fabrics [17]. However, due to the action of considerable efforts on textile materials, the quality of finished products deteriorates, which has a negative effect on their suitability and usability. These technologies do not fully provide the necessary characteristics of women's hats. Their formation is complex and requires the solution of many of technological tasks and problems. Thus, there is a need to develop innovative design technologies for the formation of women's hats made of fabrics.

2 EXPERIMENTAL

2.1 Developed of LAWE methods

One of the authors of the article, Professor Nikolay Kushevskiy, proposed to use water as a working environment, which, under the influence of external mechanical forces, creates a different formative effort. This environment is known as the Liquid-Active Working Environment (LAWE). A team of scientists, led by Professor Nikolay Kushevskiy, developed a number of ways to hydroforming the three-dimensional details of clothing, which allows expanding the design of the range of relevant industries. These methods are based on the plastic force formation of textile material in LAWE. To do this, a perforated forming element is used, on which the fabric is laid and secured with a clamping ring.

Then, the forming element, with the part attached to it, is immersed in the LAWE and the forming process is carried out. The criteria for evaluation of the quality of the formed part are its maximum height and degree of relaxation.

Seven original methods of hydroforming with the use of LAWE have been developed to ensure the quality design of the volumetric details of women's fabric hats. Appropriate experimental equipment is designed in the material for testing and implementation of the developed methods. Below is a description of each of the proposed methods.

1. Hydromechanical method of forming

With this method, the forming of the details of women's hats in three-dimensional shape is carried as follows (Figure 1): due to the work of the activator in the chamber, there appear forming vortices LAWE, which act on the fabric, fixed on the surface of the forming element.

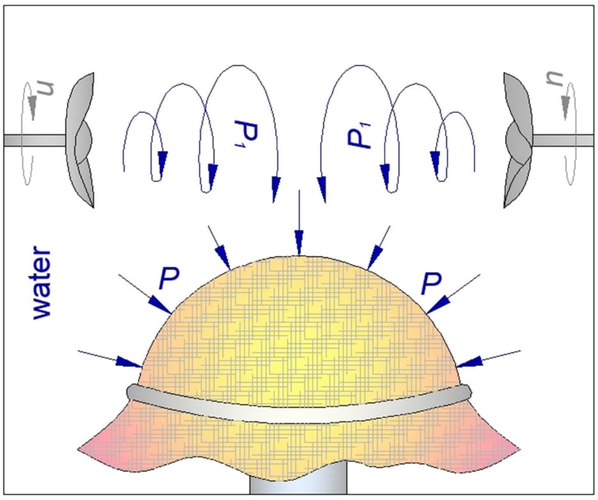

Figure 1 The action of forming loads with the hydromechanical method

The optimal parameters of the forming process are: distance from the forming element to the activator H_{act}=22 mm; rotation speed of the shaft with the activator n=3600 rpm; height of the LAWE column in the forming chamber h=100 mm; forming time t=300 s.

2. Pneumo-liquid forming method

In this case, the forming by a two-phase diffuse flow involves the use of air and LAWE flows as a force field. The compressor supplies a stream of air that is mixed with the LAWE in the forming chamber. For this purpose, a special jet is used. As a result, there is a sputtering of the LAWE onto the part of the fabric fixed to the forming element. The regulation of the kinetic energy of the two-phase flow comes from an increase-decrease in the pressure of the LAWE. This improves the dispersibility of the liquid, which as a result of combination with air has a finely dispersed state.

As a result, the penetration of the two-phase flow into the fabric structure is improved and catalyzed. As a result of the experiments, the optimal values of the parameters of the pneumo-fluidic forming (Figure 2) were obtained: the pressure of the air-water mixture P=0.12-0.16 MPa; distance from the nozzle end to the highest point of the forming element H=120-140 mm; forming time t=150-180 s.

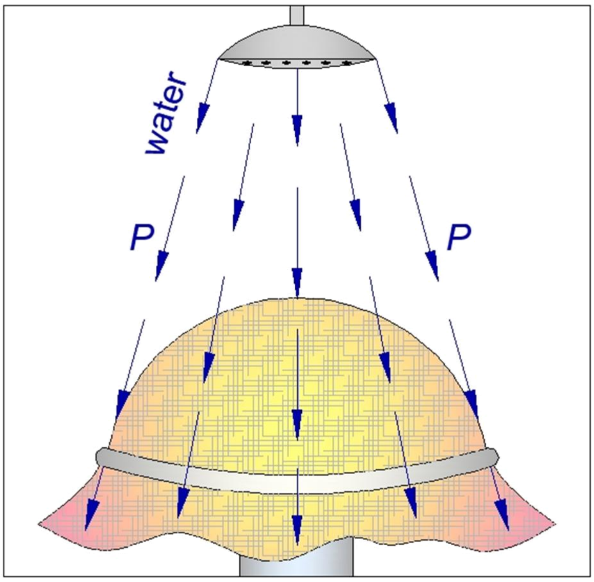

Figure 2 The action of forming loads with pneumo-liquid method

3. Hydro-jet forming method

The formation of the volumetric part occurs in a working chamber filled with LAWE due to the action of the flooded liquid jet (Figure 3).

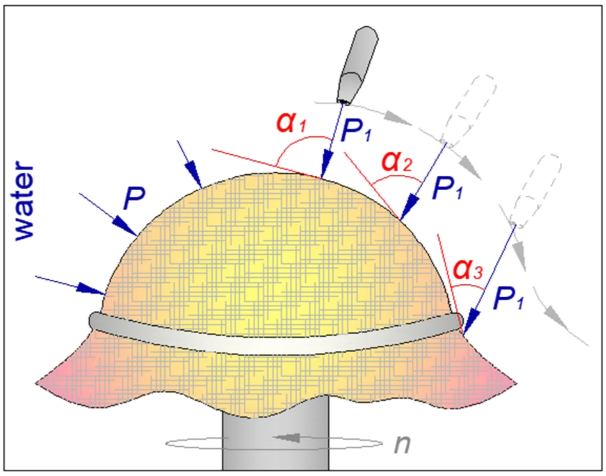

Figure 3 The action of forming loads with the hydrostream method

In the process of forming the end of the jet-forming nozzle automatically moves from the upper point to the bottom of the part. In this case, it is found at a given distance from the surface of the part and outlines a similar scaled figure of its contour. The forming element, with the part attached to it, is conditionally divided into five main sections. In each of these sections, the jet-forming nozzle further changes the angle of attack on the fabric during movement. This allows you to orient the fabric optimally during formation on the forming element. To ensure that the entire area of the part is covered by the active contact area with the controlled submerged hydro-jet, the forming element rotates about its axis. Another important factor in hydro-jet forming is the distance from the end of the jet-forming nozzle to the surface of the fabric. This value can also be changed automatically depending on the configuration of the part. The result is a different jet pressure on the surface of the part, which allows less catalyzing or inhibiting the forming process. The centrifugal loads, caused by the rotation of the forming element about its axis and the pressure of the LAWE column are also involved in the forming process. The automatization of the process is carried out by using an original computer programme and a programmed microcontroller.

The optimum parameters for hydraulic-jet forming are: pressure LAWE P=0.1-0.15 MPa; the area of the outlet of the jet forming nozzle S_{noz}=3.53 mm^2; distance from the end of the nozzle to the surface of the part l=5 mm; the rotation frequency of the shaft with the forming element and the part attached to it n=300 rpm; forming time t=140-180 s.

4. Hydrocentric forming method

With this method of molding in a chamber filled with LAWE, at the same time are found from two to four diametrically opposite forming elements (Figure 4). These elements are attached to the fabric of the hats. The forming chamber has a similar to a drum shape.

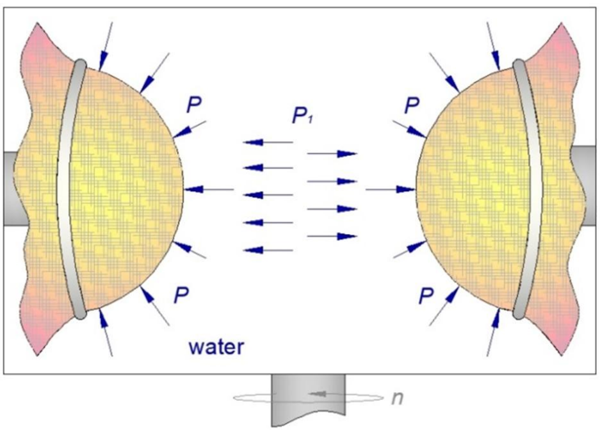

Figure 4 The action of forming loads with the hydro-centrifugal method

The main forming effort lies in the centrifugal force and circular flow of the LAWE. It occurs as a result of the rotation of the central shaft of the drum. Efforts press the fabric against the walls of the molding elements, intensely seeping it into LAWE. The optimum parameters of formation in the field of centrifugal forces are: the rotation frequency of the center shaft n=600 rpm; forming time t=120-160 s.

5. Hydraulic forming method

This method of formation involves securing of the fabric and forming element under the stage of the forming chamber (Figure 5).

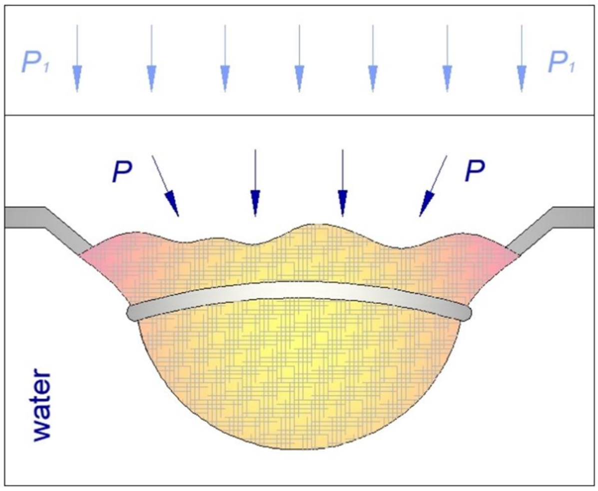

Figure 5 The action of forming loads in the hydraulic method

There are two efforts for fabric with the hydraulic method of formation of three-dimensional of hats. One of them is more intense - the pressure of the LAWE column, which acts on top P with the additional load P_1. There is no additional effort below. In this case, the process of volumetric mass transfer of LAWE to the "rough" fabric structure is performed. It promotes considerable plasticization of textile fibres.

As a result, the quality of forming improves. The nature of the forming effort is rather non-dynamic, due to its basic nature and the placement of the part below the surface of the forming element. The optimum modes for hydraulic forming under the action of LAWE pressure are: LAWE pressure P=0.13 MPa; forming time t=64 s.

6. Vacuum-liquid forming method

In this case, the main forming effort is the pressure of the LAWE column P on the fabric of the workpiece. The forming load that acts on the bottom of the fabric is vacuum pressure. As a result, LAWE filtration through the fabric occurs. In this way, the fabric of the part is placed under the forming surface. This is due to the specificity of the use of vacuum pressure.

The nature of the forming effort is quite stable. This method can be used in the formation of three-dimensional parts of women's hats, which require average indicators of fabricability. The optimal parameters of vacuum-liquid forming under the action of vacuum pressure are: vacuum pressure *V*=0.02-0.04 MPa; forming time *t*=64 s (Figure 6).

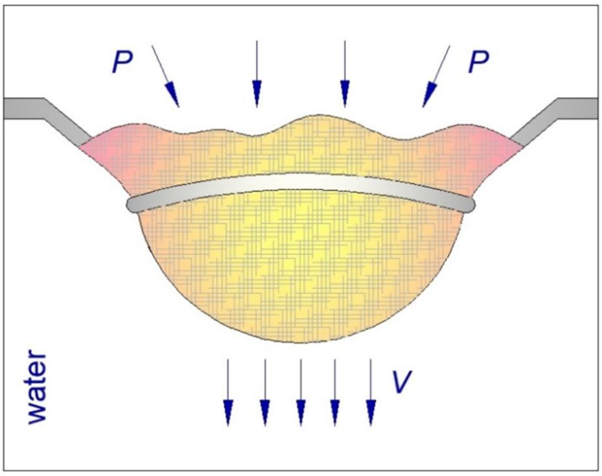

Figure 6 The effect of forming loads with a vacuum-liquid method

7. Hydro-vacuum forming method

This method involves the action of two forming loads on the fabric of the workpiece (Figure 7).

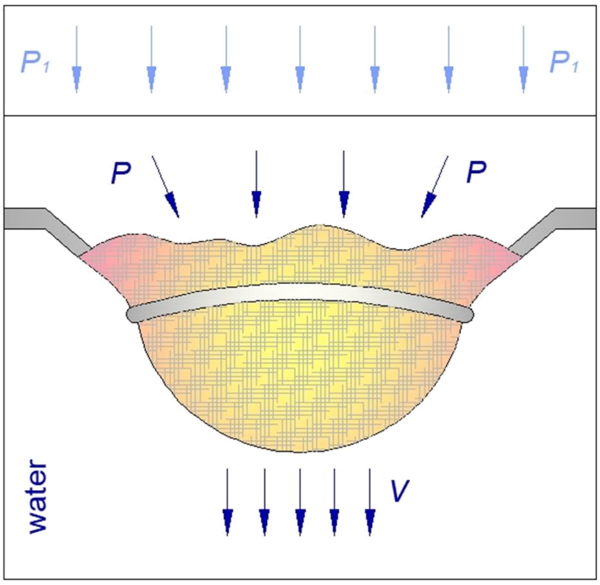

Figure 7 The effect of forming loads with the hydro-vacuum method

The forming forces, that acting on the top of the fabric part are the pressure of the LAWE column *P* with the additional load P_1. In the bottom is the vacuum pressure *V*, which also acts as a forming force. In this way, significant plasticization of the textile fibres of the part is found due to the volumetric mass transfer of LAWE to their macromolecules. The forming is performed under the plane of the forming element on which the fabric is fixed. Optimal values of the parameters of hydro-vacuum forming under the action of LAWE pressure and vacuum pressure: LAWE pressure *P*=0.22 MPa; vacuum pressure *V*=0.022 MPa; forming time *t*=140 s.

The developed technologies provide formation of a single layer of material. This is due the feature of mobility of fabric rough structure in the process of LAWE forming, by changing the network angles between the warp and weft threads. With increasing the number of fabric layers of headdress details, the optimal value of the network angle change in areas with a complex configuration is not provided. For researches were used a samples of fabrics with a diameter *d*=160 mm. This size is response to the economic aspect of technology and the proportional scale of the hat in full size.

2.2 Materials

When forming volumetric details of hats, it is necessary to take into account the physic-mechanical and physic-chemical properties of the material.

Seamless formation of volumetric details was performed by acting on the rough and thin structure of the fabric. The effect on rough structure of the fabric includes draping and shifting the angle between the systems of warp and weft threads. The methods of action on the thin structure are wet-heat treatment. They depend on the structural characteristics of the fabric. At the same time, it is necessary to use fabrics which provide mobility of threads and necessary deformation of a cell of the fabric, formed by threads of warp and weft. The paradox of the moment is determined by the fact, that with significant mobility it is need to provide a stable fixation of the detail form. Among of all existing textile fibers, wool fibers are the best option. Due to their structural construction and the presence on their surface of scales, the adhesion between the fibers is greatly increased. This allows to get a stable volumetric form. Therefore, the woollen fabrics of the suit and coat group were used to form volumetric details of the hats.

The ability to form improves with increasing fabric draping. Its degree depends on the weight and softness of material. Increasing the surface density of the fabric, weight, length of overlap of weaves and reducing the thickness contributes to improve draping. Fabrics made from plant fibers have the worst drapery, and animal - better. Stiffness is inversely proportional to the fabric draping. It increases with decreasing drapery.

The second argument for choosing woollen fabrics is to expand the possibilities of designing hats that are in harmony with clothing. The use of fabric, rather than felt or knitwear, will allow to compositionally combine all the elements of the costume.

3 suit fabrics (samples 1-3) and 3 coat fabrics (samples 4-6) were selected for the research. Fibrous composition of suit fabrics: 100% wool, coat 78% wool, 22% polyester. In the study it is taken into account a necessary structural characteristics of the fabrics, that effect on their ability to formation and form fixing: binding; binding coefficient F_1; connectivity coefficient C; filling coefficient F_2; spinning system; linear density of warp threads T_{wp} and weft T_{wf} [tex]; number of threads per 10 cm of fabric (warp P_{wp} and weft P_{wf}); surface density M_s [g/m^2]; thickness of fabric T_f [mm]; stiffness of fabric S [μH.cm^2] (warp S_{wp} and weft S_{wf}); drape coefficient Kd (warp Kd_{wp} and weft Kd_{wf}). The system of spinning of costume fabrics is comb, and coat - apparatus. The studied fabrics have the following values of structural characteristics:

Sample 1: twill binding 2/2; F_1=4; C=5.5; F_2=0.6; T_{wp}=25x2 tex; T_{wf}=25x2 tex; P_{wp}=228 threads/dm; P_{wp}=193 threads/dm; M_s=345 g/m^2; thickness T_f=0.95 mm; S_{wp}=8115 μH.cm^2 and weft S_{wf}=7582 μH.cm^2; Kd_{wp}=46 and Kd_{wf}=43.

Sample 2: basket binding 2/2; F_1=4; C=4.1; F_2=0.5; T_{wp}=33.3x2 tex; T_{wf}=33.3x2 tex; P_{wp}=163 threads/dm; P_{wp}=152 threads/dm; M_s=345 g/m^2; T_f=0.9 mm; S_{wp}=6888 μH.cm^2 and weft S_{wf}=6093 μH.cm^2; Kd_{wp}=48 and Kd_{wf} =45.

Sample 3: twill binding 2/2; F_1=4; C=4.2; F_2=0.5; T_{wp}=80 tex; T_{wf}=80 tex; P_{wp}=159 threads/dm; P_{wp}=132 threads/dm; M_s=390 g/m^2; T_f=1.45 mm; S_{wp}=13098 μH.cm^2 and weft S_{wf}=13069 μH.cm^2; Kd_{wp}=50 and Kd_{wf}=55.

Sample 4: twill binding 2/2; F_1=4; C=6; F_2=0.7; T_{wp}=125 tex; T_{wf}=125 tex; P_{wp}=140 threads/dm; P_{wp}=136 threads/dm; M_s=550 g/m^2; T_f=1.75 mm; S_{wp}=40407 μH.cm^2 and weft S_{wf}=42141 μH.cm^2; Kd_{wp}=35 and Kd_{wf}=39.

Sample 5: twill binding 2/2; F_1=4; C=5; F_2=6; T_{wp}=125 tex; T_{wf}=125 tex; P_{wp}=133 threads/dm; P_{wp}=121 threads/dm; M_s=500 g/m^2; T_f=1.56 mm; S_{wp}=12306 μH.cm^2 and weft S_{wf}=11926 μH.cm^2; Kd_{wp}=40 and Kd_{wf}=42.

Sample 6: twill binding 2/2; F_1=3; C=6.7; F_2=0.8; T_{wp}=100 tex; T_{wf}=100 tex; P_{wp}=138 threads/dm; P_{wp}=146 threads/dm; M_s=450 g/m^2; T_f=1.8 mm; S_{wp}=31535 μH.cm^2 and weft S_{wf}=31055 μH.cm^2; Kd_{wp}=36 and Kd_{wf}=31.

3 RESULTS AND DISCUSSION

The application of the seven developed methods for forming of volumetric details of women's hats in LAWE allows to diversify significantly the configurational spectrum of the use of forming elements in the technological process. This extends the design of the range of headwear for the enterprise. Consider in detail the advantages and areas that need improvement in the proposed forming methods (Table 1).

Table 1 Advantages and disadvantages of the developed methods of formation in LAWE

Developed method	Advantages	Disadvantages
1. Hydromechanical method	+ Simple design of test equipment; + Simplicity of work and formation process	- The use of static load, which does not provide active work of "rough structure" of the fabric and leads to the appearance of peeling; - The complexity of determining the process parameters at each part of the workpiece, in accordance with the properties of the fabric
2. Pneumo-liquid method	+ Prospects of use for forming fabrics that do not require significant plasticization of fibres, such as pile fabrics; + Possibility of spraying together with LAWE of apret and target penetration of its molecules to the optimum value	- Uneven distribution of static forming force, the greatest load of which falls on the lower part
3. Hydro-jet method	+ Ability to repeat the contour of the part of different configurations; + Additional loading and coverage of the entire area of the part due to the rotation of the forming element; + Ability to change the pressure and angle of attack of a flooded controlled jet as a major forming effort; + Flexibility, mobility and adaptation of the forming process due to its available automation	- Complication of the application of the apret directly in the process of forming a part due to the use of the pump for cyclic movement of LAWE
4. Hydrocentric method	+ Ability to put significant forming efforts on high density fabric	- Possibility of destructuration of low-density fabric from excessive forming efforts
5. Hydraulic method	+ Significant plasticization of textile fibres due to volumetric mass transfer of LAWE into the "rough" fabric structure	- Inhibition of the action of the forming force of the LAWE flow due to indirect contact with the surface of the fabric, as the first contact has the surface of the forming element
6. Vacuum-liquid method	+ Absence of fabric destruction due to the nature and effect of a small forming effort	- Difficulty in providing a stable shape to fabrics with low ability to form
7. Hydro-vacuum method	+ Active work of "rough" fabric structure due to the action of forming loads in the upper and lower plane of the chamber. + Significant plasticization of textile fibres due to volumetric mass transfer of LAWE into the "rough" fabric structure + Absence of fabric disruption due to the nature and effect of a small forming effort	- Effect of sufficiently static loads, which complicates the provision of a stable form to fabrics with low ability to form

After formation of volumetric part of a woman's hat, it is treated by the trim to give it steady shape. This operation is performed if it was not performed during forming process. Afterwards, the drying of the part is carried out on the forming element for 20-30 minutes. After that, the formed head of the woman's hat is ready for further technological operations. These could be connecting it to the fields, ears or visor, treatment of the open sections of the bottom. It depends on the design of the woman's hat.

The examples of the sewn women's hats with the use of the volumetric parts formed in LAWE are shown on the Figure 8.

Figure 8 Design of the women's hats with heads formed in LAWE

The general prospects of technological processes automation of formation with LAWE include the following methods: hydromechanical, pneumo-liquid and hydrocentric.

As a result, were obtained a formed heads of hemispherical shape with a diameter d_h=175-188 mm and height h=80-110 mm. These geometric parameters are within the standard sizes of hats from S to L.

4 CONCLUSIONS

It is suggested to use water as a working environment, which creates a different forming force that acts on textile materials.

Seven original methods of hydroforming using LAWE have been developed. Appropriate experimental equipment is designed and peculiarities of its functioning are given.

According to the experimental studies, the optimal parameters for forming of three-dimensional details of women's hats were determined for each of the methods:

1. *hydromechanical method* – distance from the forming element to the activator H_{act}=22 mm; rotation frequency of the shaft with the activator n=3600 rpm; the height of the LAWE column in the forming chamber h=100 mm; forming time t=300 s;
2. *pneumo-liquid method* – the pressure of the air-water mixture P=0.12-0.16 MPa; the distance from the nozzle end to the highest point of the forming element H=120-140 mm; forming time t=150-180 s;
3. *hydro-jet method* – pressure of the LAWE P=0.1-0.15 MPa; the area of the outlet hole of the jet-forming nozzle S_{noz}=3.53 mm^2; the distance from the end of the nozzle to the surface of the workpiece l=5 mm; rotation frequency of the shaft with the forming element and the part attached to it n=300 rpm; forming time t=140-180 s;
4. *hydrocentric method* – rotation frequency of the central shaft n=600 rpm; forming time 120-160 s;
5. *hydraulic method* – pressure of the LAWE P=0.13 MPa; forming time t=64 s;
6. *vacuum-liquid method* – vacuum pressure V=0.02-0.04 MPa; forming time t=64 s;
7. *hydro-vacuum method* – pressure of the LAWE P=0.22 MPa; vacuum pressure V=0.022 MPa; forming time t=140 s.

On the developed equipment women's hats of the three-dimensional form are formed and examples are given. Prospects for further research on improving the operation of the equipment are offered.

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