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# DEVELOPMENT OF A METHOD FOR THE COMBINED CONTROL OF THE HARDNESS OF WINDING TEXTILE PACKAGE

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**Abstract**

Analysis of methods for determining the hardness of the winding shows that all existing methods require a lot of labor and time. When measuring the layer-by-layer hardness, the known methods do not allow obtaining continuous values, and in the case of measuring the hardness of packages of complex shape (conical bobbins, cops, spinning cobs, etc.), it requires a calculation using cumbersome formulas. In this case, the main difficulties arise in determining the volume of the layers of the winding, which in the general case have a complex configuration, and due to defects in the winding may have an irregular shape. Obviously, the described technique is rather cumbersome, and a lot of measurements and calculations are required to obtain a graph of the change in the winding hardness along the package radius. The construction of a graph of the change in hardness along the generatrix using a special device is generally problematic, since placement of more than three sources on the device is impossible due to the size of the meters, and the construction of the curve by three points cannot be considered satisfactory. Winding hardness is one of the most important parameters, on which many technological properties of the package depend. Indeed, with an increase in the hardness of the winding, the amount of material in the same volume increases, which makes it possible to replace packages less often, both on the machine that forms them, and at the subsequent transition. As a result, the equipment useful time increases.

It was found that the hardness of the winding is closely related to its rigidity, and hence to the stability during transportation. The hardness of the winding affects the permeability of the package when it is treated with solutions. In this case, a huge role is played not only by the average value of the hardness, but also by its distribution over the layers.

**Keywords:** winding, winding hardness, layer-by-layer hardness, winding defects, winding density, technological properties, package permeability.

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## 1. Introduction

The density of the winding is one of the most essential parameters on which many technological properties of the package depend. The amount of thread on the package depends on the density of the winding, and hence the time between package changes, which affects the coefficient of useful time. In the case of unevenness of the winding density, the unwindability of the packages worsens, an uneven thread tension appears, which leads to increased breakage.

An essential issue of the quality of the winding is to ensure a uniform distribution of the winding density, both along the radius of the package and along the generatrix. Of particular importance is the unevenness of the winding density for packages subjected to liquid processing: dyeing, bleaching and cooking. Considerable attention has been paid to the measurement of the winding density in the literature. Although there are few works devoted specifically to this issue.

Among the methods for measuring the density of the winding, two main directions can be distinguished: the calculation of the density based on the results of measuring the volume of the winding and its mass; the use of physical processes, the flow of which depends on the density.

The first of these directions is the most common, since it does not require complex equipment for its implementation. The volume of the winding body is calculated by measuring its dimensions.

Moreover, preference is given to the simplest of them, since special devices for determining the size of packages are not produced by the industry.

However, when measuring the layer-by-layer density, it is not possible to obtain continuous values, and in the case of measuring the density of packages of complex shape (conical bobbins, cops, spinning cobs, etc.), a calculation is required using cumbersome formulas. In this case, the main difficulties arise in determining the volume of the layers of the winding, which in the general case have a complex configuration, and due to defects in the winding may have an irregular shape.

The second direction includes methods for measuring the winding density using penetrating radiation. This is because measurements can be made without destroying the package itself. In this case, after inspection, the package can be returned to the technological process, where its further behavior can be analyzed. The number of waste during research is reduced, which makes it possible to increase the sample size during measurements. This is also facilitated by the reduction in measurement time and the absence, in many cases, of cumbersome calculations. The combination of such methods with computed tomography [1].

It should be noted that the existing methods for controlling the winding density are not very suitable for production conditions. Methods for controlling the average winding density by its size and weight are not very informative and have limited application in production. Layer density control methods are destructive and rather laborious and therefore are not used in production conditions. Methods based on the use of penetrating radiation require complex and expensive equipment and will change exclusively for research purposes.

There is a strong correlation between the density of the winding and its hardness [2].

In this regard, conducting a study aimed at developing methods for controlling the density and hardness of winding textile packages seems relevant.

The search for a sufficiently sensitive and at the same time quickly and easily determined indicator that could characterize the degree of compaction of the material during winding led to such an indicator as the hardness of the winding.

The material closest in hardness to textile packages is rubber. The Shore method is used to measure the hardness of rubber.

The Shore-A device has an indenter with a diameter of 0.8 mm and its full stroke is 2.5 mm. Tests [3] have shown that, in its standard form, Shore device is not suitable for controlling the hardness of the winding. With such a small diameter of the indenter, there is a high probability of getting it between the threads, especially when checking the packages of cross winding. The dependence of the readings of the device on the force of pressing its body to the controlled surface was established. As a result, there was a significant variation in hardness readings. In [4], the results of studying the time elapsed from the moment of application of the load to the moment of reading the readings of the device are given, by the value of these readings. It has been found that the readings of the device decrease over time. Therefore, the duration of the load application is proposed to be normalized and set equal to 3 s.

Hand-held hardness testers for textile packages are produced by a number of factories (for example, Metrotex, Russia [5]). The Metrotex hardness tester has an indenter in the form of a hemisphere with a diameter of 5 mm and two interchangeable support pads. The adjustable force on the indenter provides hardness measurement on three scales. For hard winding, the scale is used for Shore O, and for soft winding for Shore OO and Shore OOO. Despite the modernization of hand-held devices, their readings are strongly influenced by the subjective factor, i.e., the dependence of the readings on the pressing force of the device body to the controlled surface. To eliminate this drawback, stationary devices for controlling the hardness of the winding were created.

One of these devices is manufactured by the firm «Zwick» (Germany) [6]. In this device, the monitored package is fixed permanently on the table. A measuring head is fixed above it. The package can be moved along the table using the feed screw, so that the hardness can be controlled at several points along the bobbin generatrix. To carry out the change, the lever is turned, which lowers the measuring head to the surface of the reel. The force on the measuring head is created by a weight, which ensures high stability of the measurement conditions. The creation of stable measurement conditions is also facilitated by the fact that the direction of the indenter stroke is perpendicular to the controlled surface, which is not always performed with hand-held instruments.

Since density and hardness are singular indicators of the same winding property, it is interesting to trace the relationship between density and hardness with the results of organoleptic evaluation of bobbins. According to the sensory evaluation, the bobbins are classified into «soft» and «hard». This work was carried out and the results of comparative tests are shown in **Table 1**.

**Table 1**
Comparative evaluation of package hardness and winding density

| Bobbin no. | Organoleptic evaluation | Device | | Winding density, g/cm$^3$ |
|---|---|---|---|---|
| | | Metrotex MT-343 | Zwick-3303 | |
| 1 | soft | 52.8 | 32.2 | 0.72 |
| 2 | hard | 68.0 | 52.7 | 0.86 |
| 3 | soft | 61.0 | 38.3 | 0.85 |
| 4 | hard | 76.9 | 62.5 | 0.90 |
| 5 | soft | 62.9 | 29.5 | 0.90 |
| 6 | hard | 74.0 | 50.2 | 0.91 |
| 7 | soft | 62.7 | 36.1 | 0.89 |
| 8 | hard | 74.2 | 57.3 | 0.96 |
| 9 | soft | 62.3 | 42.8 | 0.86 |
| 10 | hard | 75.7 | 69.8 | 0.89 |

The difference between hand-rated bobbins as soft and hard is:
– from 0 to 10 Shore degrees when measuring density;
– from 7.4 to 35.3 Shore degrees according to the Zwick hardness tester;
– from 5.1 to 24.1 Shore degrees according to the Metrotex MT-343 hardness tester.

There is a close correlation between the readings of the Zwick and Metrotex MT-343 devices. Despite the higher measurement accuracy, stationary instruments for measuring the hardness of packages are not widely used. Hand-held devices are widely used in the textile industry, and not only for the control of bobbins, but also for control of other types of winding, including roving spools, warping rolls and rolls of fabric [7–10]. The devices described make it possible to control the hardness only on the surface of the packages, which is another disadvantage.

The developments given in [11] are an attempt to solve this problem. The proposed device is equipped with a needle, with which the threads of the thread are pierced from the end of the bobbin to a certain depth. The diameter of the needle and the depth of piercing depend on the structure of the filaments and the fibrous material. The needle is placed in a bearing support installed in the holder of the portable handle. At the end of the needle, located in the recess of the cage, a spring is fixed, the free end of which is connected to a limiting rod acting on the pointer arrow. The lower end of the arrow is located near the scale with divisions corresponding to the measured hardness of the thread winding in the bobbin. When piercing the bobbin with a needle, the handle is rotated clockwise, while the torque of the needle and the spring changes to the maximum deflection of the arrow corresponding to the hardness of the winding. When measuring with an indenter, regardless of its shape, the hardness is determined at one point.

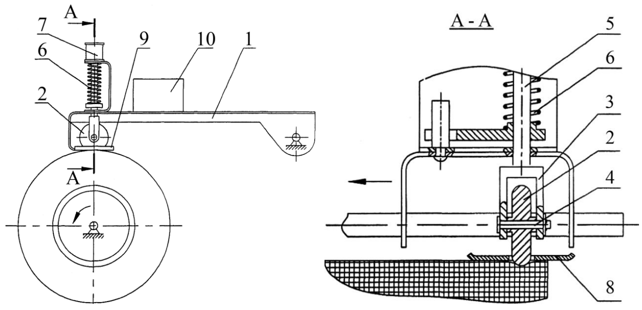
To obtain reliable information about the hardness of the package as a whole, a number of measurements are carried out at several points on the surface of the package, after which the obtained data are averaged. Based on the symmetry of the winding body, it can be assumed that the points located at an equal distance from the end of the package should have the same hardness and the variation in readings during measurements is explained by random factors.

In [12], a method is proposed for obtaining the average value of hardness for points located at an equal distance from the end of the package. The device contains a flexible inextensible thread at one end fixed on a rigid support. A pre-tension weight is suspended at the other end of the thread. This end of the thread is thrown over a low-inertia roller. The thread wraps around the bobbin under investigation, which is attached to the support in one turn. An arrow is attached to the roller, with the help of which the angle of rotation of the roller can be measured on the scale. After installing the bobbin into the loop formed by the thread, zero is set on the scale, after which a measuring weight is suspended from the free end of the thread. Under the action of it, the loop of the thread is pressed into the winding body. The length of the buttonhole decreases and the weights move downward by the amount of the decrease in the length of the buttonhole. In this case, the thread turns the roller and the arrow due to frictional forces. The scale is graduated in units of winding hardness.

## 2. Materials and methods of research

Further development of methods for monitoring the hardness of packages is a method of continuous monitoring of the hardness of the winding [13]. When it was created, the task was set to continuously monitor the hardness of the package winding both in the circumferential and axial directions. This problem is solved due to the fact that the measuring element continuously moves relative to the outer surface of the package, simultaneously in the circumferential and axial directions. The measuring element is mounted on a lever and is pressed against the winding surface, and a roller with a toroidal outer surface is used as an indenter.

The claimed continuous method for controlling the hardness of the winding is as follows (**Fig. 1**). Lever 1 with the help of weight 10 presses the foot 8 against the winding surface. The indenter in the form of a wheel 2 passes through the slot in the tab 8 and is also pressed against the winding surface. The spring 6 is selected so that the force created by it is less than the force created by the weight 10, reduced to the point of contact of the indenter with the winding body. Since the foot area is much larger than the contact pad of the indenter, the pressure under the indenter exceeds the pressure under the foot. Due to this, the indenter is introduced into the winding body. The amount of this penetration depends on the hardness of the winding and serves for its quantitative assessment. Due to the introduction of the indenter into the winding body, it and its associated parts, the fork 3 and the rod 5, move relative to the lever 1, which is converted by the sensor 7 into an electrical signal proportional to the hardness of the winding.




*a* *b*

**Fig. 1.** Device for continuous control of winding hardness:
*a* – general view; *b* – cross section of the measuring roller assembly

For continuous control of the winding hardness, the bobbin holder, together with the winding, receives rotation from the drive, and the lever 1 moves translationally parallel to the package axis. In this case, a continuous signal is generated at the output of the sensor 7, which characterizes the distribution of hardness over the entire winding surface. The effectiveness of the described method for controlling the hardness of the package is confirmed by research [14].

It is obvious that the described method for controlling the hardness of packages has increased information content and will allow for better quality and in a short time to debug the winding mechanisms to eliminate rejects when processing packages with solutions.

However, despite the obvious advantages of the proposed method, it has disadvantages that arise when using hardness instead of density as an indicator characterizing the uniformity of the package structure. This is, first of all, the impossibility of describing the characteristics of thin layers of the winding using hardness and connecting this property with the structural features of the winding body.

The method of density control based on determining the volume of the winding layers with the help of technical vision means is devoid of this drawback. Using the data on the shape of the generatrices of such a package, it is possible to calculate the volume of the winding body. If to make the appropriate measurements as the package is unwound, as is done in the process of controlling the winding structure [15], then it is possible to determine the change in volume between two successively received frames. This approach makes it possible to create a new method for determining the layer-by-layer winding density and calculating the average density based on it.

Let's consider in more detail the process of determining the change in the volume of the winding body during the time elapsed between two successive frames.

The bobbins are shown in **Fig. 2**. Lines $k$ and $k$+1 on it correspond to the shape of the generators at successive times.

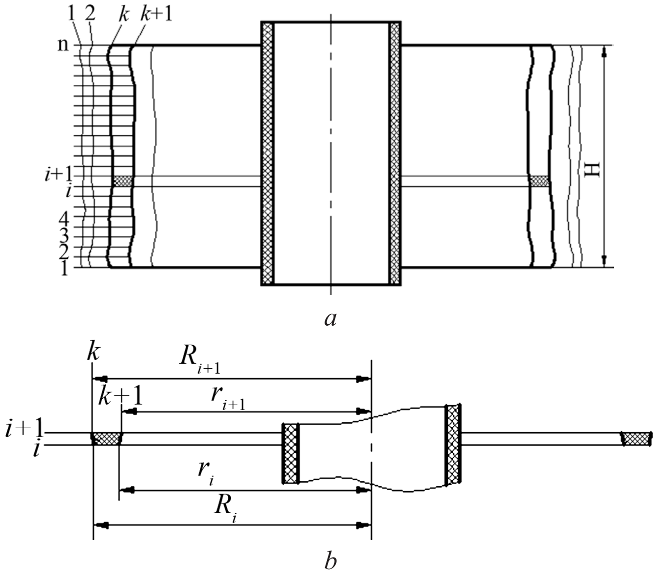



**Fig. 2.** To determine the change in the volume of the winding body: *a* – numbering of layers in the body of the bobbin; *b* – dimensions of an elementary layer

The coiled part of the package is a ring. Let's conditionally cut it with n parallel planes normal to the bobbin axis. One of such rings bounded by planes numbered i and $i$+1 is shown in the lower part of the figure. Due to the fact that the generators of the winding bodies are generally non-rectilinear, the inner and outer radii of the ring n of the plane i and $i$+1 are not equal. In view of the smallness of the ring thickness equal to $H/n$, the inner and outer generators of the ring can be considered straight lines and the volume of the ring can be calculated by the formula:

$$V_i = \pi \frac{(R_{i+1} - r_{i+1}) + (R_i - r_i)}{4n} H(R_{i+1} + R_i + r_{i+1} + r_i). \tag{1}$$

Summing up the volumes of all rings, let's determine the volume of the coiled part of the winding body:

$$V_k = \sum_{i=1}^{n} V_i. \tag{2}$$

To determine the mass of the coiled part of the package, a weight sensor must be included in the winding density control device. Its work must be synchronized with the work of the camera, i.e. the values of the package weight should correspond to the moment of shooting the corresponding frame. In this case, the mass of the wound thread is determined by the formula:

$$M_k = \frac{G_k - G_{k+1}}{g}, \tag{3}$$

where $G_k$ and $G_{k+1}$ – the weight of the bobbin at the moment of shooting the $k$-th and $k$+1-th frames; $g$ – the acceleration of gravity.

The density of the winding in the selected ring can be calculated by the formula:

$$\gamma_k = \frac{M_k}{V_k}. \quad (4)$$

This density can be related to the radius of the bobbin corresponding to the average radius of the ring, i.e.:

$$R_k = \frac{R_{i+1} + R_i + r_{i+1} + r_i}{4}. \quad (5)$$

Formulas (1)–(5) make it possible to obtain a layer-by-layer distribution of the winding density in a bobbin of arbitrary shape. This distribution objectively characterizes the suitability of the bobbin for treatment with solutions (bleaching, dyeing).

**3. The results of the study of the geometric and technological parameters of textile packages**

The result of the described method of experimental determination of the distribution law of the winding density is the creation of a software and hardware complex, the hardware part of which is protected by a patent of the Russian Federation for a useful model [16].

**Fig. 3** shows a schematic representation of the proposed device. The proposed device consists of three blocks: a block for controlling the shape and density of winding I, a block for winding the thread and controlling its tension II, and a processing block III, implemented on a computer.

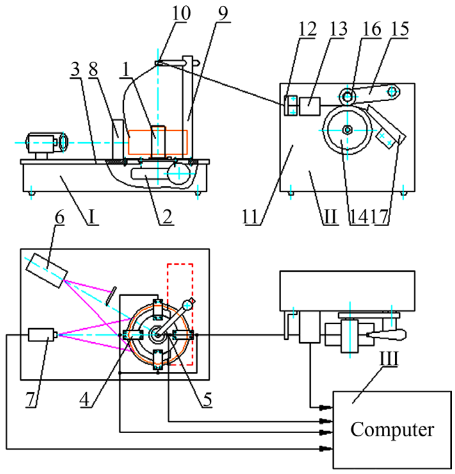



**Fig. 3.** Diagram of a device for a comprehensive assessment of the technological parameters of cross-wound packages

Block I includes: a bobbin holder 1, on which a controlled package is installed, an illuminator 6, a video camera 7 and a shutter 8. The bobbin holder 1 is installed on the output shaft of an electromechanical drive 2, which is attached to the plate 3 of the device using four elastic elements 4. On elastic elements strain gauges are placed to control the weight of the winding on the package. A sensor 5 of its position is installed next to the bobbin holder, which forms a pulse when the mark on the bobbin holder passes by it. The axes of the illuminator 6 and the camera 7 lie in the same plane perpendicular to the axis of the bobbin holder and intersect with it. The shutter 8 is located in such a way that one of its edges is parallel to the axis of the reel holder and touches the optical axis of the illuminator 6. The width of the shutter allows covering half of the light flux coming from the illuminator 6. The angle between the optical axes of the illuminator 6 and the camera 7 is in the range from 30° to 45°. The value of this angle determines the accuracy of determining the diameter of the package and the width of the generatrix. When the angle decreases less than 30°, the conversion factor of the controlled value (winding radius) into the measured value (the distance of the edge of the shade of the shutter from the optical axis of the camera) becomes too small, which does not allow ensuring the required measurement accuracy. When it is increased more than 45°, the illumination of the bobbin surface near the optical axis of the camera becomes insufficient to obtain a clear image, which is used to analyze the winding structure (the presence of rope and tape winding). On the plate 3 there is a stand 9 with a guide eye 10, designed to control the position of the thread when unwinding the bobbin.

The structure of block II, for winding the thread and controlling its tension, includes a guide eye 12 located on the frame 11, a thread tension sensor 13, a pulling shaft 14 and a pressure roller 16 located on a pivoting arm 15 air (not shown in **Fig. 2**).

The video camera 7, the bobbin holder position sensor 5, the yarn weight sensors on the package 4 and the yarn tension sensor 13 are connected to the computer, where the corresponding signals are transmitted for processing.

The device works as follows. The controlled bobbin is installed on the bobbin holder 1. The thread unwound from it passes through the eyes 10 and 12 into the pulling pair formed by the shaft 14 and the pressure roller 16. The free end of the thread coming out of the pulling pair is directed by air draft to the nozzle 17, from where it is transported to the storage (not shown in **Fig. 3**). During operation, the shaft 14 rotates from a drive installed inside the bed 11, and provides continuous winding during the entire time of the package inspection. The package installed on the bobbin holder rotates at a low speed, while the entire side surface of the package passes in the field of view of the camera 7. The shadow from the shutter 8 also appears in the field of view of the camera, and the distance from the optical axis of the camera to the shadow is proportional to the radius of the corresponding section of the package, and the vertical the size of the shadow corresponds to the width of the package. This data in the form of a shadow image is transmitted to a PC. In the central part of the frame there is an image of the package surface, according to which, using the appropriate software, it is possible to quantify the distance between the turns on the package surface, i.e., the presence or absence of rope or tape winding. Due to the rotation of the bobbin, the entire package surface passes through the field of view of the camera. Load cells installed on elastic elements 4 generate an analog signal proportional to the weight of the package, the bobbin holder 1 and its drive 2. This signal is transmitted to the computer, where the weight of the thread remaining on the bobbin is calculated. The analysis of the parameters is carried out in one package revolution. The signal for the beginning and the end of taking the corresponding data goes to the computer from the sensor 5. During the entire time of winding the bobbin from the sensor 13, a signal proportional to the thread tension is transmitted to the computer. On the basis of this signal, according to the method [17], it is possible to determine such a generalized indicator of the quality of winding as unwinding.

Since the winding conditions during the operation of the device for different bobbins are the same, the tension characterizes the overall quality of the package, which is evaluated using software by calculating the tension peaks and their distribution along the radius of the package.

The block diagram of the data processing process in the device for the integrated control of the packing parameters is shown in **Fig. 4**. Blocks 1 and 2 in the diagram show the bobbin weight sensor and the video camera, respectively. These both devices are combined into a block for obtaining primary data 3. To ensure synchronous data retrieval, the device includes a gating signal generator 7, which generates pulses that provide a frame capture and a signal proportional to the current weight of the bobbin. Removal of primary data is performed while unwinding the bobbin. Data from the unit for receiving primary data is stored in the database 6. This makes it possible to use the received data in the subsequent processing with various adjustable parameters. The data on the weight of the bobbin is stored as an array in block 4, and the videos in block 5. The processing of videos includes the following operations:

– dividing the video into frames (block 8) using methods;

– selection from each frame of the central part (block 9), the height of which is equal to the height of the bobbin image, and the width is 80 pixels. This part of the image is used to analyze the winding structure according to the methods described in Chapter 6 of this work (block 11);

– extraction of a generator from each frame of the image (block 9);

– obtaining from the image of the generatrix of its profile, the length of the generatrix and the average radius of winding (block 10);

– data on the weight of the package is used to calculate in block 12 the current value of the weight of the package.

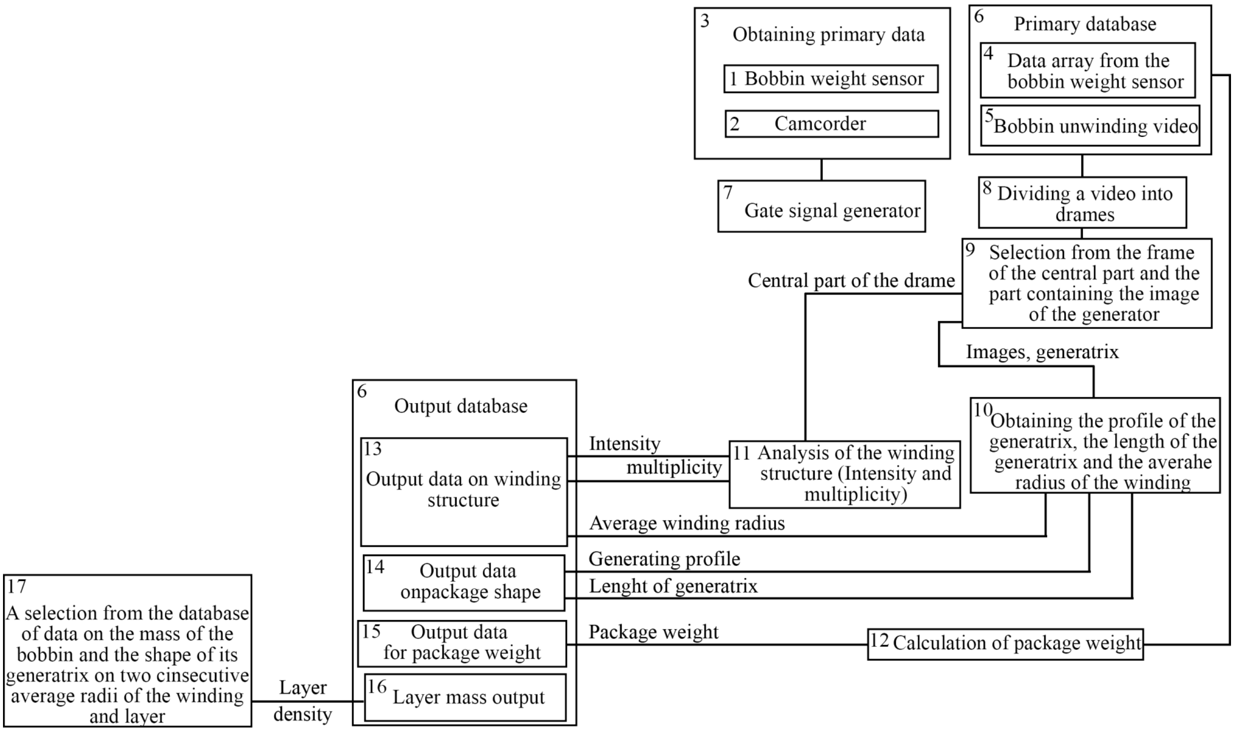



**Fig. 4.** Block diagram of the data processing process in the device for complex control of the packing parameters

The received data related to each time point specified by the strobe signal generator are stored in the database (block 6). The data from the database allows to prepare a report on the structure of the winding and the shape of the package. Block 17 reads two sequentially arranged data on the shape of the package and its weight, on the basis of which, according to formulas (1)–(5), it calculates the mass of the winding layer and enters it into the corresponding field of the database 6. These data are used to prepare data on the distribution of the winding density by layers.

The end result of the analysis is a graphical and tabular presentation of the dependencies of almost all technological parameters of the package under study. Some of them are shown in **Fig. 5–8**.

The data obtained make it possible to reasonably approach the choice of the modes of forming the package and control the quality of their manufacture.

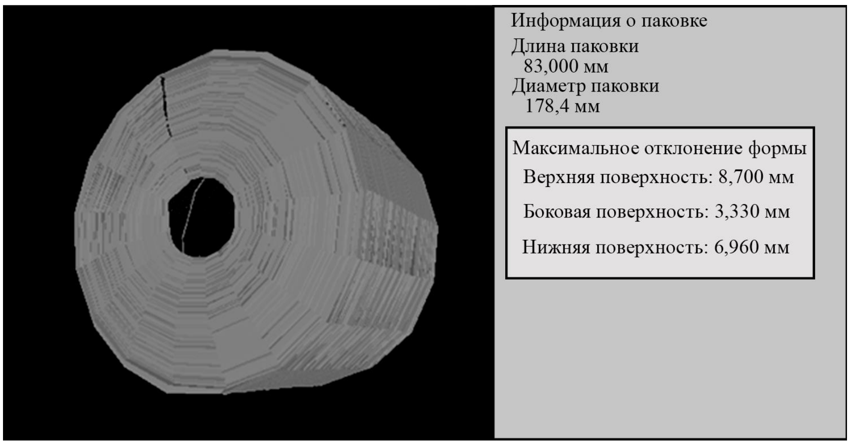



**Fig. 5.** Output of the analysis results in the form of a 3D model of the package

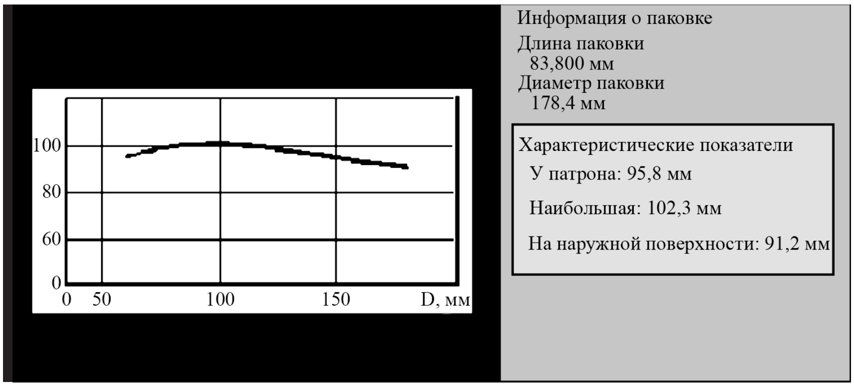



**Fig. 6.** Output of the generating package shape analysis results

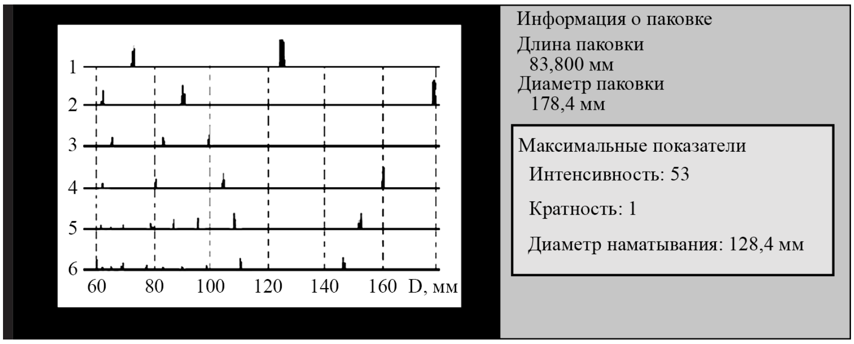



**Fig. 7.** Output of the package structure analysis results

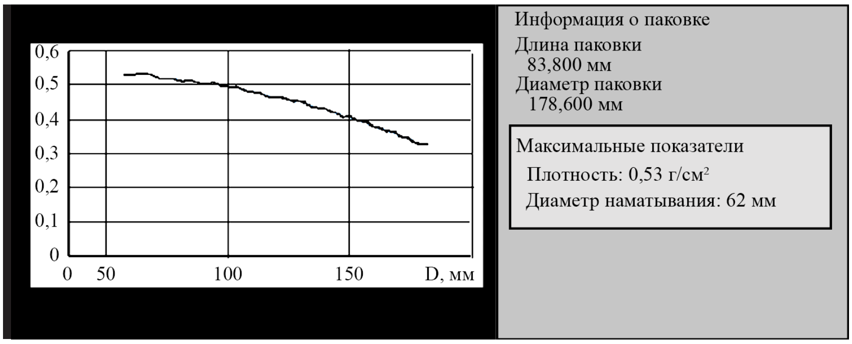



**Fig. 8.** Output of winding density analysis results

**4. Discussion of the results of the study of the geometric and technological properties of textile packages**

Obtaining, as a result of the application of the proposed control method, a fairly complete set of properties of textile packages is explained primarily by a systematic approach to their determination. This is the shape of the packages presented in the form of their 3D model (**Fig. 5**) or the shape required for the analysis of the section, for example, the generatrix (**Fig. 6**); quantitative assessment of the parameters of the winding structure tied to the winding diameter (**Fig. 7**); distribution of winding density in the package body (**Fig. 8**).

A feature of the method for controlling the parameters of textile packages described in the article is an integrated approach based on the fact that the primary data obtained as a result of measurements are used to obtain a complete set of quality indicators, and not each separately.

The proposed technique, due to the automation of the control procedures and the simultaneous measurement of the entire set of required parameters of the winding body, makes it possible to solve the problem of a reasonable choice of technological parameters of winding that ensure the required quality of winding.

The advantage of the proposed technique is a significant simplification of the procedure for analyzing the quality of textile packages, a reduction in the timing of its implementation, as well as an increase in the information content of the analysis. The advantage of the integrated approach used in the proposed method is especially noticeable when comparing it with the methods described in the scientific literature. So in [1], the method of computed tomography is used, which allows obtaining data on the shape of the package and the distribution of density, but does not allow obtaining information on the structure of the winding. In [10], a method for controlling the winding structure is proposed, which does not allow analyzing the shape and distribution of the winding density, which shows the undoubted advantage of the method proposed in this article.

The proposed control method is intended for textile packages. Its application in other industries using winding structures, such as the production of composites, coils that are components of electrical circuits, etc., seems to be problematic.

It is known that the main parameter that determines the ability of textile packaging at subsequent technological transitions is tension and its unevenness. Therefore, a further direction in the development of the described control method is the inclusion of high-frequency thread tension sensors in its composition. The readings of these sensors must be synchronized with the data on the current reeling diameter and the structure of the outer layer of the package. Their comparison will reveal the reasons for the uneven tension of the thread when it is unwound from the package.

When creating devices that register geometric and structural parameters simultaneously with tension, a number of problems arise. The main contradiction is between the need to register tension with a high sampling rate and the processing of a large amount of data obtained in this case from sensors. Most of this data is uninformative and should be discarded. Further development of the methodology for controlling the parameters of textile packages is the development of special algorithms for solving problems associated with processing a large amount of uninformative data.

## 5. Conclusions

1. As a research result, a technique has been developed for an automated complex analysis of the parameters of textile packages, which allows obtaining a full range of parameters characterizing the quality of winding. The proposed technique differs from the known ones by an integrated approach, as a result of which it became possible to assess the mutual influence of factors that are independently analyzed within the framework of known techniques, for example, the density and structure of the winding. The proposed technique is new and opens up new, additional opportunities for improving the winding technology and the design of winding mechanisms.

2. Combining the control of the winding structure and the package shape, carried out by the methods of technical vision with the control of the distribution of the winding density, allows to reduce the time for control and the consumption of materials for samples.

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