Розглянуто питання, пов'язані з вибором одиничних показників для оцінки якості форми пакувань хрестового намотування і створенням алгоритмів їх автоматизованого визначення.

Розроблено метод оцінки якості форми пакувань хрестового намотування за комплексним показником. Для обґрунтування одиничних показників, методом експертного опитування, проведено ранжування дефектів форми пакувань за ступенем їх впливу на придатність пакувань до переробки на наступних технологічних переходах.

Для кількісної оцінки кожного з названих дефектів форми бобіни визначені поодинокі показники, що дозволяють кількісно оцінити їх вплив. Розроблено вирішальні правила і алгоритми для їх обчислення на підставі отриманого раніше масиву даних про координати точок поверхні бобіни. Встановлено бальна оцінка впливу кожного з одиничних показників, що характеризують дефекти намотування на придатність пакувань до переробки на наступних технологічних переходах.

Комплексна оцінка якості форми пакування може бути отримана методом середньозваженого показника. Середній зважений показник будується як залежність, аргументами якої є одиничні показники якості і параметри їх вагомості.

Виходячи з цього, була отримана залежність для розрахунку комплексного показника якості форми бобіни. Чим більше значення приймає цей показник, тим вище якість контрольованого пакування.

Проведено оцінку застосовності розробленого комплексного показника для аналізу форми пакувань. Для цього проведено аналіз партії пакувань, який підтвердив відтворюваність процесу аналізу форми пакування за допомогою запропонованого комплексного показника; а також відповідність оцінок, отриманих за запропонованою методикою, візуальними оцінками.

Метод комплексної кількісної оцінки форми пакувань дозволяє проводити оптимізаційні експерименти і на їх основі призначати такі регульовані параметри мотальних механізмів, які дозволять отримувати пакування необхідної якості. При розробці нового мотального обладнання можна буде закласти необхідні кошти регулювання процесу намотування

Ключові слова: розробка алгоритмів, одиничний показник, форма бобіни, дефекти намотування, комплексний показник, середньозважений показник

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CONSTRUCTION OF ALGORITHMS TO AUTOMATICALLY DETERMINE INDIVIDUAL INDICATORS WHEN ASSESSING THE SHAPE QUALITY OF CROSS-WOUND PACKAGES

M. Nuriyev
Doctor of Technical Sciences, Professor
Department of Standardization and Certification*
E-mail: mehman62@mail.ru
G. Jabbarova
Department of Consumer Goods Expertise*
E-mail: qenire.cabbarova@mail.ru
*Azerbaijan State University of Economics (UNEC)
Istiglaliyyat str., 6, Baku, Azerbaijan, AZ 1001

1. Introduction

One of the most common types of textile packages are the cross-wound packages [1]. That is explained by the fact that they meet a wide range of requirements that technologists put forward to them. These requirements include: a compact flow of threads when processing at subsequent transitions, uniform permeability when treated with solutions, suitability for long-term storage and transportation without loss of quality. Meeting these requirements is ensured by the corresponding properties of the cross-wound package: its shape, structure, and the stressed-deformed state of a package's body. Those properties of packages that satisfy technological requirements are considered to be essential. Maintaining them at the required level is a criterion for choosing rational structural parameters for winding mechanisms and technological modes of winding. The indicators characterizing these properties shall be adjusted in accordance with the requirements to a particular package.

In this regard, it is a relevant task to conduct a study aimed at developing algorithms in order to automatically determine individual indicators for estimating the shape of cross-wound packages.

2. Literature review and problem statement

It is known that violating the conditions for bobbin formation results in a series of defects that complicate its processing at subsequent technological transitions. One of the most important components of the cross-wound bobbin's quality is its shape. Paper [1] theoretically substantiated the relationship between the structure of winding, detachment of turns from the end of the package, and the number of breaks when winding a package. Authors of [2] reported results of their study into distortions in the package shape related to the violation of winding structure. It is shown that they can lead to a violation of the thread layout law, which in turn results in additional distortions in the shape of the wound bobbins. This effect is similar to a positive feedback in the systems of automatic control, which leads to a loss of the system's stability. Paper [3] reported results from modeling a process to unwind a thread from the package. It was shown that violating a package shape leads to uneven tension that adversely affects the process of knitting at knitting machines where bobbins are used as carriers of a feeding thread. Patent [4] was issued on a device designed to eliminate uneven tension that always occurs when unwinding bobbins with defects in their shape. Article [5] gives an example of an opto-electronic system for inspection of defects on a thread, which often arise as a consequence of violating the shape and structure of the package. The two latter sources show that an attempt at processing bobbins with defects requires considerable complexity of technological equipment implying the introduction to it of specialized controlling devices, designed to address the negative consequences related to the violation of a package shape.

The main types of the winding structure defects, manifested in the form of the violation of its shape, are: yarn winding; deviation of the end side from straightness; ledges at end faces of a package; ledges on the forming; flutings at the end sides of a package; deviation of bobbin from cylindricity or taper.

Each of the specified defects is estimated based on an individual indicator, many of which do not make it possible to derive the assessment of quality.

For the most common defect, yarn winding, we suggested a quantification procedure [1]. It implies the following.

Schematic arrangement of thread turns when the unwanted structures form, for example, in yarn winding, is shown in Fig. 1. When forming yarn winding, the thread turns are stacked at the same place with a frequency equal to denominator n in the transfer ratio of bobbin to the yarn guide. Paper [6] shows that the larger n, the fewer threads in a yarn, and the less dangerous it is for causing breakages at unwinding the bobbin. Visually, a yarn winding manifests itself in the form of projections at the lateral surface of the package. The paper addresses the procedure to control the shape of completed packages. In this case, it is not possible to check the existence of plait winding by analyzing the shape of a lateral surface, because plaits typically form at smaller diameters of winding and are hidden by threads above. It is possible to check the presence of plait winding based on analysis of the shape of end sides.

As shown in [7], plait winding is accompanied by violation of the law of thread placement, specified by the yarn guide. That results in that most threads go beyond a package's end side, which has a negative impact on the capability of packages to unwind. In addition, plaits have a greater density than that of the main body in winding, which leads to uneven dyeing of threads in packages.

Paper [8] shows that plait winding leads to a distortion in the profile of the shape-forming bobbin relative to the shape of the profile of the generating bobbin. Authors of [9] have confirmed the specified relationship using an analysis of the graphical model of a package as an example, and have demonstrated that the plait winding is accompanied by that the threads go beyond the end of the package. The turns that go beyond the end side represent local increases in the height of the profile, which could be detected by analyzing data on the coordinates of the end-side's profile for each of the cross sections. The harmful effect of plait winding on the subsequent processing of bobbins increases with an increase in the number of threads in the plait. This increases the height of the irregularity at the side end of the package, caused by that the threads go beyond it. An indication that an irregularity at the side-end surface is due to plait winding, rather than to other reasons, could be that it is not observed along all meridional cross sections and that thicker sections are formed simultaneously at both end-sides of the package.

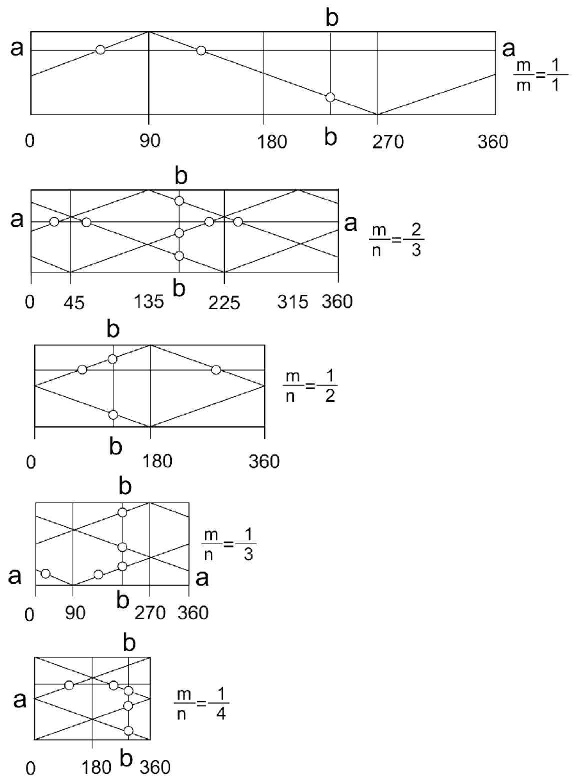

Fig. 1. Schematic of plait winding

To determine the number of threads per a plait, we define the way this magnitude relates to the height of an irregularity at the end side of the package that accompanies plait winding. When forming a plait and when approaching the end side, the threads theoretically should be placed on top of each other. It is clear that such a structure is unstable and the threads to be laid later would tumble down, forming the structures depicted in Fig. 2. Dependence of height h of the structure, which forms in this case, on the number of threads in it, can be calculated from formula:

$$h = d\left[1 + (n-1)\frac{\sqrt{3}}{2}\right], \quad (1)$$

where n is the number of threads in a plait, d is the conditional estimated thread diameter [10].

In this case, parameter d is derived from expression:

$$d = 0.0357\sqrt{\frac{T}{\delta}}, \quad (2)$$

where T is the linear density of threads, tex, δ is the volumetric weight of a material mg/mm^3.

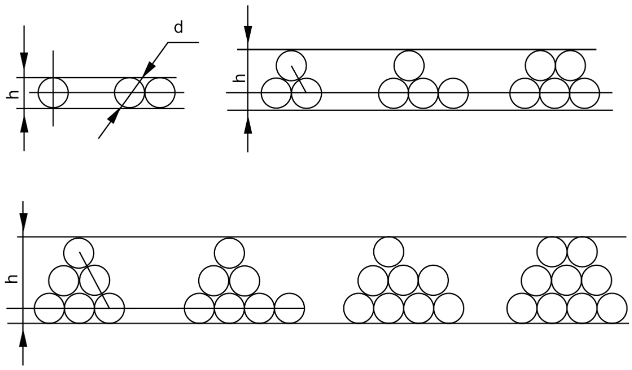

Fig. 2. Arrangement of threads in the plait's cross-section

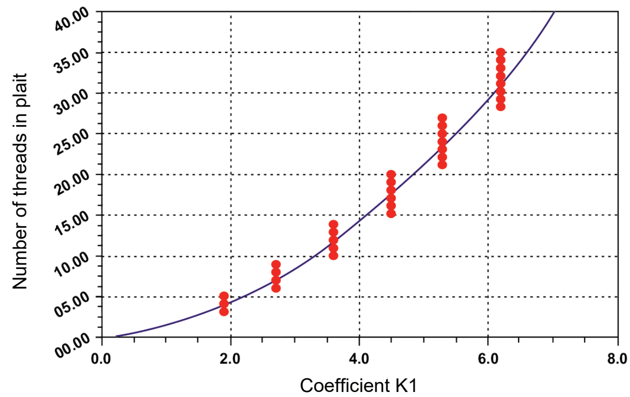

Fig. 3. Dependence of number of threads in a plait on coefficient K_1

Let us denote $K_1 = 1 + (n-1)\sqrt{3}/2$, hereafter we term it a structural factor, since it depends only on the arrangement of threads in a plait.

Collapse of threads in a contact is defined by their transverse rigidity and pressure forces. We account for them using a coefficient K_2, which must be determined experimentally. Consequently, in order to calculate the height of plait formations, we derive the following formula:

$$h = K_1 K_2 d. \quad (3)$$

Values for coefficient K_1 that depend on the number of threads in a plait are given in Table 1.

Considering coefficient K_1 to be an argument, and the number of threads in a plait to be the function, it becomes possible, following the approximation of values given in Table 1, to derive a dependence to determine the number of threads in a plait on the height of structures formed by threads when they go beyond the end side of the package. We applied parabola as an approximating function:

$$h = dK_1\left(a + bn + cn^2\right), \quad (4)$$

where *a, b*, and *c* are the coefficients whose values are equal to $a=-0.0748$; $b=0.928$ and $c=0.673$.

Initial data and result of the approximation are demonstrated by the chart in Fig. 3.

The resulting pattern (4) underlies determining the decisive rules for calculating the magnitude for an individual indicator to characterize the plait winding.

For other defects, decisive rules are stated in [10].

Paper [11] suggested an indicator characterizing the structure of cross-wound winding throughout the entire package. To derive it, the package must be unwound. This is unacceptable under industrial conditions because it requires a fairly large amount of time and it is a destructive method of control. The unwound thread does not return to the production process.

Study [12] describes a real-time system that controls stacking of a fiber thread in winding when forming cylindrical parts made of composite materials. The system makes it possible to control deviations in the shape of winding due to cylindricity. Control of other defects in the shape is not implied by the system.

Paper [4] reported a technical solution for winding bobbins of a strictly defined shape that provides their easy replacement at equipment that utilizes them as feeding packages. Resolving such a task required control over the shape of winding; however, the individual indicators used for this task were not revealed.

Study [13] shows a winding density control system that applies the individual indicator «tiered winding density». The application of such an indicator for assessing the quality of winding ensured the alignment of winding density along the radius of the bobbin. However, other indicators of quality were not taken into consideration that made it impossible to estimate it for the package in general.

Work [14] reports data about quality control that complies with the ISO service requirements. It is noted that these requirements could be met only by developing appropriate integrated indicators based on a series of individual indicators that make it possible to quantify properties of an object.

Individual indicators, to be found by the decisive rules stated in [15], do not make it possible to estimate the shape of a package in general. This is primarily due to that the influence of individual indicators on the quality of a package as a whole is not uniform. In addition, there may be occasions when some packages have a low value for certain indicators and high for others; in this case, comparing their quality is difficult. To address this issue, it is necessary to devise a generalized integrated indicator, which would take into consideration the extent to which each of the individual indicators affects quality of the package. Analysis of individual indicators suggest the appropriateness of applying a method of expert estimates as a basis for constructing a generic quality indicator for the cross-wound packages.

Table 1

Dependence of coefficient K_1 on the number of threads in a plait

Number of threads	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Number of layers, *n*	1	1	2	2	2	3	3	3	3	4	4	4	4	4	5	5	5	5	5	5	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7
K_1	1	1	1.9	1.9	1.9	2.7	2.7	2.7	2.7	3.6	3.6	3.6	3.6	3.6	4.5	4.5	4.5	4.5	4.5	4.5	5.3	5.3	5.3	5.3	5.3	5.3	5.3	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2

3. The aim and objectives of the study

The aim of this study is the construction of algorithms in order to automatically determine individual indicators for assessing the shape of cross-wound packages and in order to form an integrated indicator on their basis.

To accomplish the aim, the following tasks have been set:

– to build a system of a series of individual indicators to assess the shape of cross-wound packages;

– to derive decisive rules for the algorithmic calculation of the proposed individual indicators;

– to propose and substantiate a formula to calculate the integrated quality indicator for a bobbin shape;

– to analyze a batch of packages that could confirm the reproducibility of the process for assessing the shape of a package using the proposed integrated indicator.

4. Procedure of construction and results of studying the integrated indicator to characterize the quality of cross-wound packages

4. 1. Development of a system of individual indicators for assessing the shape of cross-wound packages

The method of expert estimations [16] that underlies the procedure for constructing an integrated indicator implies that experts perform an intuitive-logical analysis of the problem followed by the quantification of judgments and by the formal processing of results. A comprehensive use of intuition (unconscious thinking), logical thinking, and quantitative assessments followed by their formal treatment, makes it possible to obtain an effective solution to the problem. The generalized opinion of experts, obtained from processing, is accepted as a solution to the problem.

To implement the procedure of an expert survey, a group of experts was formed. A general requirement to the formation of the group of experts was a capability to deal effectively with the problem.

Reliability of a group expert assessment depends on the total number of experts within the group, the fractional composition of various professionals in the group, on the characteristics of experts.

To estimate individual indicators describing the shape of the package, we formed a group of 18 experts. Nine experts were employees from quality control departments at the Mingechaur textile plant (the city of Mingechaur, Azerbaijan Republic). The other nine are specialists from the Azerbaijan University of Economics (UNEC) (the city of Baku, Republic of Azerbaijan). The UNEC experts are specialists in textile technology and statistical methods for quality control in manufacturing.

When compiling a group of experts, we took into consideration their experience in work related to the direction of the survey, as well as their experience of scientific work in the field of quality assessment in textile industry. In addition, we took into consideration the capability of experts to judge independently. According to the classification of types of tasks addressed in expert surveys, as shown in [16], the task of this work refers to the quantification of specified objects.

Among such types of survey used in a collective examination as discussion, questioning, interviewing, a collective method for generating ideas, we selected a questioning without feedback. The questioning was carried out in a single step and the experts were not informed about the results of the survey. Selection of this very variant of a survey is explained by that the survey is the most effective and most common type of survey because it makes it possible to combine in the best way the information support to experts and their autonomous creativity.

Paper [16] that addresses this issue recommends using a scale of assessment with an odd number of points. In our case, we used a nine-point scale for a more accurate assessment of the impact of defects in the shape of a package on its suitability for the further processing.

When conducting a survey, the experts were given a questionnaire given in Table 2. Based on a preliminary survey, we chose 6 criteria that estimate the quality of package winding using its shape. To estimate each parameter, we set individual indicators and stated decisive rules to define them.

Table 2

Expert survey questionnaire

Using a nine-point scale, specify the degree of negative impact of each of the identifies defects in yarn winding on its suitability for further processing in weaving production in the form of a weft or warping				
No.	Defect name	Point		
1	Maximum deviation of end side from straightness, mm	2	5	10
2	Ledges of bobbin's end side, at height, mm	1	2	5
3	Slub at end sides (at slub width), mm	3	5	10
4	Plait winding, number of threads	5	10	20
5	Corrugations at ends near the cartridge at width, mm	5	10	20
6	Deviation of bobbin from taper, degrees	0.5	1	2

Each criterion (defect in winding) was assigned three fixed values for an individual indicator. An expert had to rank each of these values for a criterion based on a nine-point scale.

4. 2. Derivation of decisive rules for the algorithmic computation of individual indicators

To build a generic package quality indicator based on its shape, one must have the fullest information on each criterion. To this end, we calculated averaged values of ranks for each fixed value and, paired with respective values for criteria, we used them for the interpolation by a straight-line equation applying a least square method. Functions that are obtained by interpolation are the decisive rules the for algorithmic computation of the proposed individual indicators. They were calculated using the embedded function of MS Excel; results are given in Table 3.

Based on the data acquired, we constructed dependence charts. The charts are shown in Fig. 4–9. These charts testify to the impact of an individual criterion on the quality of winding.

When ranking objects, experts typically disagree in opinions about the problem being solved. Given this, there is a need to quantify the degree of agreement among experts. To this end, a coefficient of concordance, or agreement, among experts is computed [16].

Table 3

Dependence equations

No. of entry	Title of individual indicator	Dependence equations of point-based estimate Y_i on X_i – individual indicator
1	Maximum deviation of end side from straightness, mm	$Y_1 = 0.83 \cdot X_1 + 0.34$
2	Height of ledge at bobbin's end side, mm	$Y_2 = 2.92 \cdot X_2 - 0.48$
3	Width of slubs at bobbin's end side, mm	$Y_3 = 0.59 \cdot X_3 - 0.05$
4	Plait winding, number of threads	$Y_4 = 0.23 \cdot X_4 + 4.28$
5	Width of corrugations at end sides near the cartridge, mm	$Y_5 = 0.35 \cdot X_5 + 1.78$
6	Deviation of bobbin from taper, degrees	$Y_6 = 3.38 \cdot X_6 - 0.56$

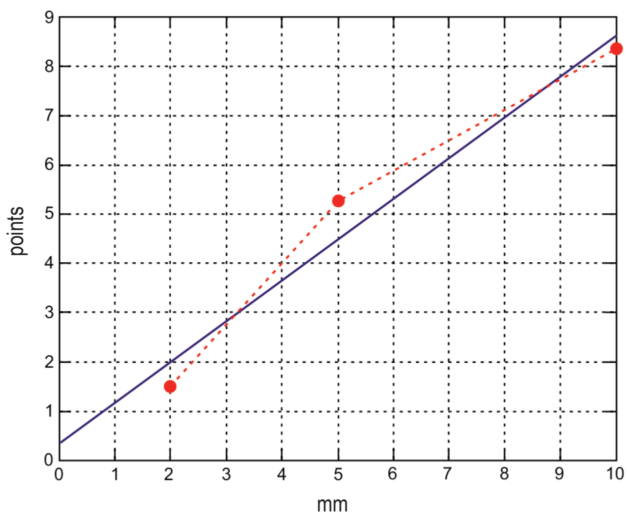

Fig. 4. Maximum deviation from straightness

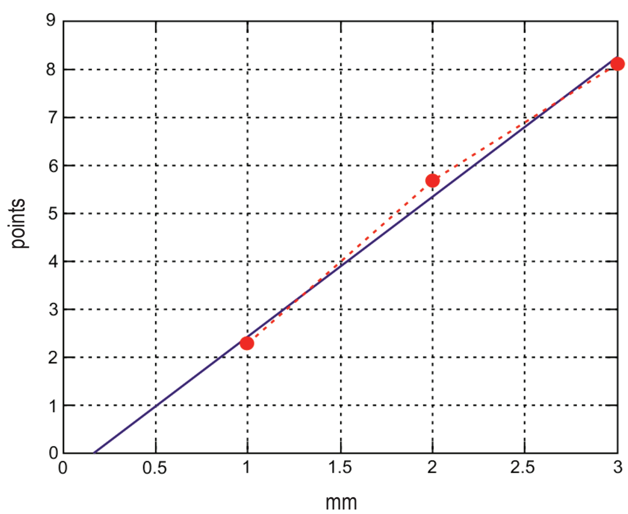

Fig. 5. Ledges in bobbin's end side

Concordance coefficient W is defined from expression:

$$W = D / D_{max}, \tag{5}$$

where D is the actual variance of the summary (ordered) estimates given by experts; D_{max} is the variance of summary (ordered) estimates for the case when expert opinions completely coincide.

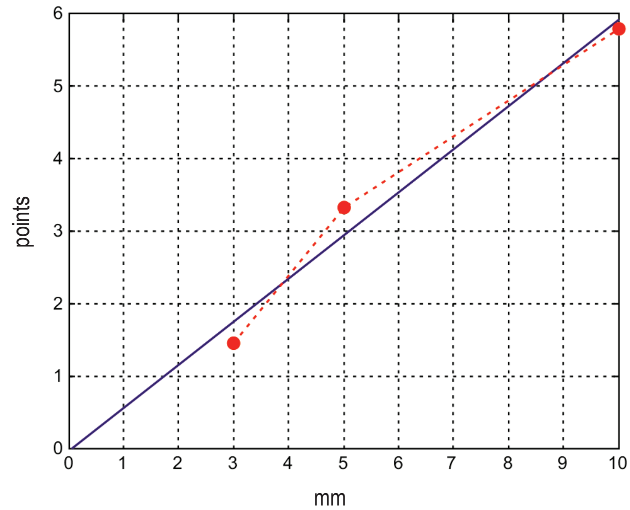

Fig. 6. Slubs at end sides (at width of slubs)

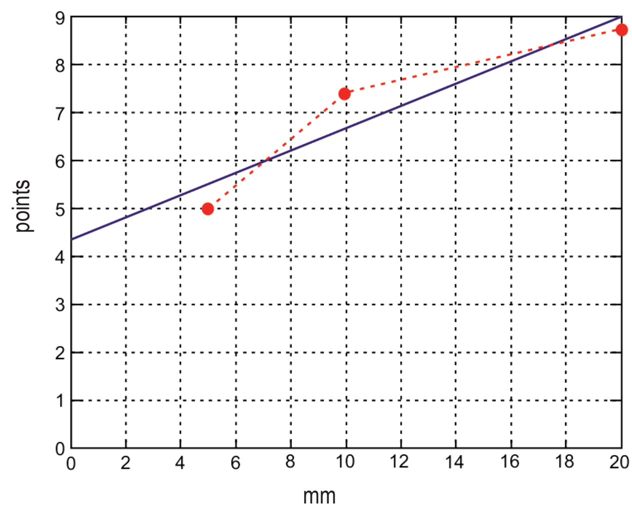

Fig. 7. Plait winding, number of threads

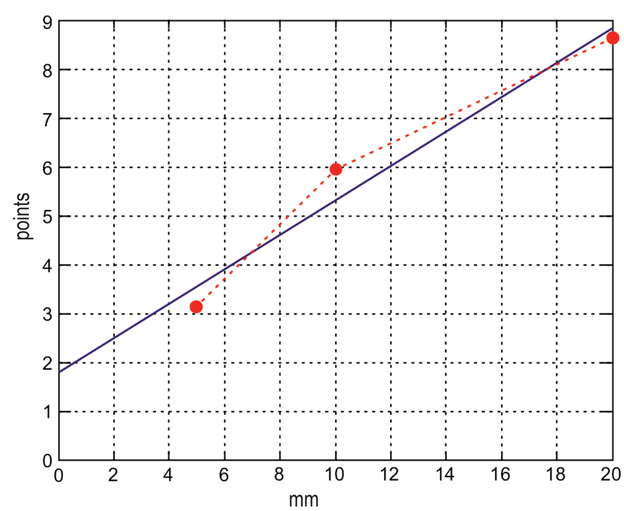

Fig. 8. Corrugations at end sides near the cartridge at width

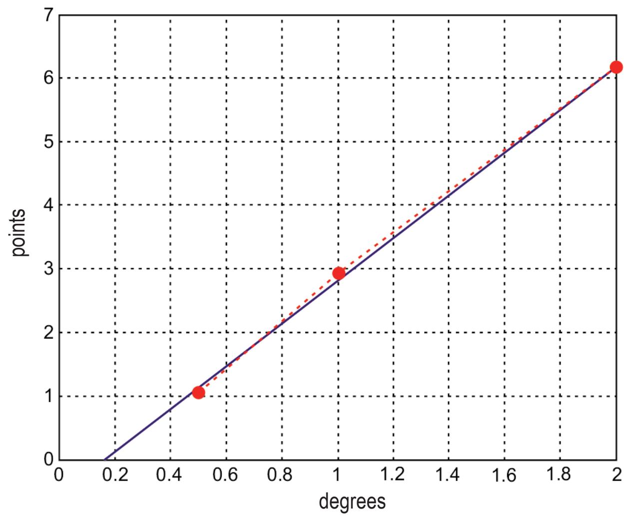

Fig. 9. Deviation of bobbin from taper

The concordance coefficient magnitude can vary from 0 to 1. At W=0, there is no coherence, that is the link between estimates by various experts is missing. At W=1, experts' opinions fully coincide.

To decide on using the assessments received from experts, it is necessary that the coefficient of concordance (W) should exceed the specified (normative) value for W_n, that is:

$$W > W_n. \quad (6)$$

We can accept W_n=0.5.

It is believed that at W>0.5 the activities by experts are coordinated to a better degree rather than not consistent.

The result of calculation in line with formula (6) is the following derived value for the coefficient of concordance, for the survey performed: W=0.86.

$$X_{val} = m(n-1)W, \quad (7)$$

where n is the number of criteria, m is the number of experts.

At the number of degrees of freedom v=n–1, we find a tabular value for X^2_{tabl}. If it turns out that $X^2_{val} > X^2_{tabl}$, the hypothesis on the consent among experts is accepted.

Because the estimated value for $X^2_{val} = 263$ at the number of degrees of freedom v=17 and the significance level q=95 % turned out to exceed the tabular value $X^2_{tabl} = 27.59$, the hypothesis about consistency of experts is accepted.

4. 3. Substantiation of the formula to calculate the integrated indicator for the quality of a bobbin's shape

To build an integrated indicator characterizing the shape of a package, it is necessary to establish the desirability of accounting for each of the individual indicators. Because the desirability of integrating each indicator was not specified by experts, we can use as such a characteristic the mean value of points per an indicator (Table 4).

Next, we computed the indicators' weight coefficients in line with a procedure given in [17].

The weight factor of the i-th indicator is equal to:

$$m_i = \frac{a_i}{\sum_{i=1}^{n} a_i}, \quad (8)$$

where a_i is the point estimate of the i-th indicator, n is the number of indicators that can be taken into consideration when assessing the quality of a product.

The weight coefficients obtained are given in Table 5.

Table 4

Point estimates of indicators

No. of entry	Title of individual indicator	Point-based estimate to account for indicator
1	Maximum deviation of end side from straightness, mm	5.0
2	Height of ledge at bobbin's end side, mm	5.4
3	Slub width at bobbin's end side, mm	3.5
4	Plait winding, number of threads	7.0
5	Width of corrugations at end sides near the cartridge, mm	5.9
6	Deviation of bobbin from taper, degrees	3.4

Table 5

Weight coefficients

No. of entry	Title of individual indicator	Weight coefficient
1	Maximum deviation of end side from straightness, mm	0.167
2	Height of ledge at bobbin's end side, mm	0.178
3	Slub width at bobbin's end sides, mm	0.117
4	Plait winding, number of threads	0.231
5	Width of corrugations at end sides near the cartridge, mm	0.195
6	Deviation of bobbin from taper, degrees	0.112

A comprehensive assessment of product quality can be obtained using a method of the weighted average [17]. The weighted average is constructed as a dependence whose arguments are quality indicators and parameters for their weight:

$$Q = F(m_i, q_i), \quad (9)$$

where q_i is the relative value for the i-th indicator.

The relative value for q_i is chosen based on the significance of the indicator. If an indicator is positive, that is, an increase in it leads to an increase quality, then:

$$q_i = X_i / X_b, \quad (10)$$

where X_i is the value for the i-th quality indicator; X_b is the value for the i-th basic indicator. If the indicator is negative, then the inverse relation holds.

Proceeding from data in Tables 2, 4, one can express a comprehensive indicator of quality. It is the sum of indicators, since each indicator affects the quality of a product, regardless of a value for another indicator. The value for the basic indicator defines the lower limit of the scale based on which we measured parameters:

$$Q=\frac{0.167\cdot 2}{0.83\cdot X_1+0.34}+\frac{0.178}{2.92\cdot X_2-0.48}+ +\frac{0.117\cdot 3}{0.59\cdot X_3-0.05}+\frac{0.231\cdot 5}{0.23\cdot X_4+4.28}+ +\frac{0.195\cdot 5}{0.35\cdot X_5+1.78}+\frac{0.112\cdot 0.5}{3.36\cdot X_6-0.56}. \quad (11)$$

The higher the value for this indicator, the higher the quality of the controlled package. It should be noted that a given indicator can accept values in the range from 0 to 1, and the criteria's values are always greater than zero.

4. 4. Analysis of reproducibility of the process to assess the shape of a package when applying the proposed integrated indicator

To estimate the applicability of the constructed method to analyzing the package shape, we measured several batches of packages with both cylindrical and conical shape, and produced at different machines. Given the results of measurements based on the established values for point estimates and the weight coefficients for each indicator, we calculated a comprehensive indicator from formula (11).

The results derived are summarized in Table 6.

Batches of packages No. 1 and No. 2 were produced under the same conditions. They were analyzed in order to determine the reproducibility of the process for determining the integrated indicator of shape when using the proposed method.

The variances in samples were compared based on the Fisher criterion [18].

It was established that the estimated value for the Fisher criterion is:

$$F_P=\frac{S_2^2}{S_1^2}=1.501, \quad (12)$$

less than the tabular value for this criterion F_T=4.28 with confidence probability p_D=0.95 and the number of degrees of freedom for output parameters f_1=f_2=6. Hence, the difference between variances is statistically negligible.

The mean values Q_{CP} for both samples were compared based on a Student's criterion [18].

To this end, we calculated variance:

$$S^2\{Q\}=\frac{(m_1-1)S_1^2\{Q\}+(m_2-1)S_2^2\{Q\}}{m_1+m_2-2}= =\frac{(7-1)0.04^2+(7-1)0.049^2}{6+6-2}=2.401\cdot 10^3, \quad (13)$$

where m_1 and m_2 are the number of repetitions in the respective samples.

Next, we determined the estimated value for a Student's criterion:

$$t_P=\frac{|Q_{CP1}-Q_{CP2}|}{\sqrt{S^2\{Q\}}}\sqrt{\frac{m_1 m_2}{m_1+m_2}}=0.071. \quad (14)$$

Table 6

Integrated indicators to assess the shape of different packages

Batch No.	Characteristics of packages in a batch	Package No.	Integrated indicator Q_i	Mean value per a batch, Q_{CP}	Root mean square deviation S_Q
1	Tapered package with a small angle of taper 2°. Larger diameter 280 mm. Wound at the spinning pneumo-mechanical machine R 40 OE made by Rieter. Yarn, greige, linear density 25 tex	1	0.964	0.925	0.04
		2	0.973		
		3	0.918		
		4	0.947		
		5	0.859		
		6	0.917		
		7	0.898		
2	Same as batch No.1	1	0.956	0.927	0.049
		2	0.897		
		3	0.917		
		4	0.943		
		5	0.972		
		6	0.967		
		7	0.834		
3	Conical package with a taper angle 13°. Larger diameter 250 mm. Wound at the winder machine M-150. Cotton, yarn, linear density 56 tex	1	0.748	0.806	0.067
		2	0.856		
		3	0.776		
		4	0.809		
		5	0.926		
		6	0.729		
		7	0.802		
4	Cylindrical package for dyeing. Diameter 200 mm. Wound at the winder machine MM-150. Bleached linen yarn, linear density 56 tex	1	0.71	0.691	0.055
		2	0.777		
		3	0.731		
		4	0.701		
		5	0.624		
		6	0.659		
		7	0.633		
5	Cylindrical package. Diameter 250 mm. Wound at the spinning pneumo-mechanical machine PPM-120. Cotton yarn, linear density 29 tex	1	0.687	0.737	0.041
		2	0.802		
		3	0.718		
		4	0.751		
		5	0.774		
		6	0.980		
		7	0.728		
6	Cylindrical package. Diameter 200 mm. Wound at the spinning machine PSK-225-ShG. PAN yarn, linear density 32x2 tex, painted in red	1	0.699	0.645	0.113
		2	0.674		
		3	0.582		
		4	0.489		
		5	0.791		
		6	0.747		
		7	0.534		

The tabular value for this criterion was determined at confidence probability p_D=0.95, and the number of degrees of freedom $f=m_1+m_2-2=10$. It amounted to t_T=2.228. Since $t_P<t_T$, the difference in the mean values is statistically negligible and the shape control process is reproducible when applying the proposed integrated indicator.

Visual assessment of the shape of packages from batches No. 1–6 suggests that they generally meet the requirements of technologists. However, this evaluation is not accurate and does not make it possible to compare the quality of packages.

Quantitative evaluation based on an integrated indicator is more convenient when adjusting the equipment. It provides for a finer gradation of quality assessment.

It follows from the data given in Table 6 that they can be successfully used to control the shape of packages made from cotton, linen, and staple fibers.

5. Discussion of results of applying the integrated quality indicator for cross-wound packages

The developed comprehensive package quality indicator makes it possible to quantify the shape of a package and to judge its suitability for the following technological stages. This is due to that the comprehensive quality indicator makes it possible to obtain a quantitative estimate, which is more sensitive to adjustable parameters.

Special features of the method imply the establishment of correspondence between the results of organoleptic evaluation given by experts and the instrumental estimation for each individual indicator.

The proposed method is limited by the accuracy of instrumental procedures that underly determining individual indicators and by the stochastic character of properties of textile materials.

A possible drawback of the method is the use of linear models to establish a link between the point-based and instrumental evaluations of individual indicators. It should be noted that increasing the accuracy when moving to more complex models might not substantiate the costs associated with their construction.

The main application of the proposed method for the evaluation of quality of cross-wound packages is associated with that it could be used when adjusting equipment under industrial conditions. It is known that the package shape is largely influenced by a thread linear density, its elastic-deformation, and frictional characteristics. Therefore, the winding mechanism should adapt to processing threads of respective kind. Such adjustments are enabled at winding mechanisms in many machines by adjustment settings. Some of them are given in Table 7. There are no recommendations regarding the establishment of specific values for these parameters, except for a winding tension.

The method for the integrated quantitative estimation of the package shape, described in the present work, makes it possible to conduct the optimization experiments and, based on them, to assign such adjustable parameters that would make it possible to receive packages of the required quality.

When designing new spinning and winding equipment, the application of the proposed method is even more efficient, because a newly developed structure has a much larger number of adjusted design parameters than that in standard equipment. Each of them must be set in such a way as to ensure the required quality of a package, both in in terms of shape and in other technological parameters.

Table 7

Adjustment of winding mechanisms at certain machines for spinning and weaving preparatory production

No.	Adjusted parameter		PPM-120	BD-200S	M-150	MM-150	AM-150
1	Shift in layout		+	+	–	–	–
2	Taper		+	+	+	+	+
3	Angle of layout		+	+	–	–	–
4	Tension (advancement of winding relative to release)		+	+	+	+	+
5	Periodicity in the angle of layout		+	–	–	–	–
6	Pressing effort	by load	–	–	+	+	+
		by spring	–	–	–	–	+
7	Dry friction damper		–	+	–	–	–
9	Electric breaker		–	–	+	+	+

6. Conclusions

1. Based on an expert survey, we devised a system of six individual indicators for evaluating the shape of cross-wound packages:

– Maximum deviation of the end side from straightness, mm;

– Ledges in a bobbin's end side, at height, mm;

– Slubs at end sides (at slub width), mm;

– Plait winding, number of threads;

– Corrugations at end sides near the cartridge at width, mm;

– Deviation of a bobbin from taper, degrees.

The specified indicators make it possible to move from a subjective assessment to qualitative instrumental.

2. We have built decisive rules that represent functions to convert the quantitative estimates of defects in winding, selected as individual indicators, into a point-based estimate of the adverse effect on a winding quality. Decisive rules were obtained by using a method of expert estimations; they make it possible to algorithmize the calculation of a point-based estimate for the proposed individual indicators and thus significantly accelerate the procedure for obtaining them, as well as exclude influence of an operator's subjectivity on the results of assessment.

3. We have suggested and substantiated a formula to calculate the integrated indicator for a bobbin's shape quality, which makes it possible to raise the procedure of quality assessment to the qualitatively new level, to significantly accelerate it, and completely eliminate the subjectivity of results.

4. We have analyzed a batch of packages and confirmed the reproducibility and the adequacy of assessment of the package shape when using the proposed integrated indicator. This allows us to recommend the method for assessing the shape of packages, using an integrated indicator, for application under industrial conditions to adjust technological equipment and when designing new models of winding mechanisms for textile machinery.

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