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# DETERMINING THE DEPENDENCES FOR CALCULATING A CONVERSION SCALE OF PROFILE HEIGHT OF THE CONTROLLED PACKING SURFACE

**M. Nuriyev**

Doctor of Technical Sciences, Professor\*

E-mail: mehman62@mail.ru

**I. Seydaliyev**

PhD, Associate Professor\*

E-mail: ilham.seydaliyev@mail.ru

**I. Recebov**

PhD, Senior Lecturer\*

E-mail: ilqar67@mail.ru

**K. Dadashova**

PhD, Senior Lecturer\*

E-mail: d.kamale@mail.ru

**T. Musayeva**

Lecturer\*

E-mail: taranamusayeva@mail.ru

\*Department of Standardization and Certification

Azerbaijan State Economic University (UNEC)

Istiglaliyyat str., 6, Baku, Azerbaijan, AZ1001

*Отримано залежності для розрахунку масштабу перетворення висоти профілю контрольованої поверхні пакування від конструктивних параметрів пристрою, що реєструє. Отримані залежності можуть використовуватися при розрахунку пристрою реєстрації форми бобін, а також для оцінки похибок визначення відповідних параметрів форми*

*Ключові слова: метод тіньової проєкції, масштаб перетворення, висота профілю, оцінка похибки, дефекти намотування*

*Получены зависимости для расчета масштаба преобразования высоты профиля контролируемой поверхности наковки от конструктивных параметров регистрирующего устройства. Полученные зависимости могут использоваться при расчете устройства регистрации формы бобин, а также для оценки погрешностей определения соответствующих параметров формы*

*Ключевые слова: метод теневой проекции, масштаб преобразования, высота профиля, оценка погрешности, дефекты намотки*

## 1. Introduction

One of the most important properties of the technological process of textile production is its stationarity. At present, all major processes on all technological transitions are performed without human intervention. An operator performs refilling of input and output packings only and eliminates breaches in the technological process, related to the tear of product. In this case, the first of these functions is largely automated. Existing attempts to automate the tearing are not so successful. Therefore, ensuring the stationarity of processes is a relevant task. One way to achieve it is to stabilize the tension when winding from the feed packing, which can be achieved by excluding from the technological process the packings with defects of shape, at whose winding the jumps in stretching occur. This can be achieved by controlling the shape of winding when working out designs of winding mechanisms and recommended modes of their operation.

## 2. Literature review and problem statement

The issue of control over shape is given serious attention by textile machinery manufacturers. Sufficiently full control

of shape at the test phase of new winding equipment makes it possible to identify in a timely manner possible defects in the shape of winding. Information about defects is the basis for analysis of their causes. This ultimately enables equipment manufacturers to eliminate the causes of defects in winding in the process of working out the design, as well as to formulate operating conditions of the equipment, allowing to avoid the occurrence of such defects.

The most acceptable are the optical methods in combination with the automated tools of pattern recognition. The lack of mechanical contact with the controlled body allows conducting measurements in the process of unwinding the bobbin. At sufficiently high speed of reading out and processing the information, this makes it possible to obtain high resolution and, therefore, detect the smallest defects on the body of winding.

Thus, [1] proposes an optical system for the evaluation of defects on yarn on packing, in which the source image was obtained with the help of video microscope to be subsequently transferred to a personal computer.

In [2], an analysis was run on the influence of quality of preparing the yarn packing to weaving. It is shown that the quality of bobbin substantially affects the resulting quality of the products of textile production. Violations of bobbin

shape are often the cause of uneven thread stretching that leads to the instability in technological process.

[3] describes a quality control system of yarn packing as the basis for ensuring the quality of finished products. In that article, the yarn defects are evaluated by the method of image processing. Initially, the images were made using the scanner, after which the resulting images were edited using several filters. Then yarn defects were identified based on their geometrical shape and surface area. As shown by results, the image processing methods are quite reliable in assessing the number and type of yarn defects.

In order to implement quality control of the formed packings, a number of technical solutions protected by patents have been recently proposed.

Thus, a device [4] to control the size and shape of a bobbin, used in a winding automated machine in the process of winding the thread, is equipped with a controlling head, installed prior to a bobbin holder, or in the area of motion of a bobbin to a storage bunker. Controlling head is equipped with a source of light with scattering lens to guide the beam to the bobbin. Reflected light beams are directed to a system of photo detectors that transmit the signal to a microprocessor processing unit, which compares signals to the reference ones that match the assigned shape of a bobbin. Signals from the controlling unit are sent to the drive unit of a winder head for adjusting the rotation frequency of a bobbin holder. A shortcoming of the device is that the control is applied to only one of the ends of a bobbin, and in this case only the bobbin's unroundness is defined by the given end, as well as deviation from the specified diameter. Therefore, the device does not allow for comprehensive control of geometrical parameters of a packing body. A similar drawback is demonstrated by a set-up in [5].

In the device from [6], a source of illumination is the laser beam that scans a bobbin surface, which allowed a considerable increase in resolution.

The device described in [6] is the development of systems based on scanning the image of a bobbin by the laser beam, such as Beltro-Lis [7], manufactured by Barmag AG (Germany). The system records the presence of torn elementary threads, stains and dirt, as well as controls the contours of packings. The operation principle of the system is based on the optical measurement of distances that take place regardless of the degree of gloss of the controlled packings. As a light source, it uses the laser beam. It scans the end surface of a packing, usually in the direction of its radius. The light reflected from the packing is captured by the detector that registers not the amount of reflected light but the light spot position. A location of the light spot is a measure of height. As the detector operates regardless of the amount of reflected light, the device is suitable for scanning the packings of yarn made of natural fibers. It is also suitable for partially oriented yarns and fibers, obtained in the process of texturing with stretching. Automation completely eliminates manual operations and considerably reduces control duration.

A further development of the system Beltro-Lis is the system Lis-200 [8], manufactured by Lenzing-Instruments (Austria) in cooperation with Barmag AG (Germany). The system allows control of geometrical parameters of a bobbin (diameter, saddling and swelling). In addition, to evaluate such parameters of thread as the existence of filling end of thread, bundle winding, etc. The system that has a modular structure makes it possible to determine all of the listed characteristics or only some of them. The use of laser

technology enables registration of very small defects in bobbins invisible to the human eye. The system is equipped with an automated transport vehicle and a robot, which provide for the reception of bobbins, setting them into a place for control and fulfilling other activities related to the control of bobbins. Throughout the control process, no human touches the bobbin. Control of a bobbin takes ~9 s. In the course of one hour the system monitors more than 400 bobbins. The systems based on scanning the examined area of packing by the laser beam are quite complex and, as a result, expensive, they require specially trained personnel to operate them.

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### 3. The aim and tasks of the study

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The aim of present study is to create a device that combines universality with the possibility of full and continuous control of the packing shape.

To achieve the set aim, the following tasks are to be solved:

- to receive a dependence to determine the scale of shadow transformation at the surface of packing into a digital image;
- to establish dependences of the scale of transformation on the design parameters of device;
- to provide an informed choice of design parameters of the device for obtaining initial information.

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### 4. Results of research into the process of converting the shadow into a digital image

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In order to receive complete information about the shape of packing, it is necessary to have a profile image by sections at end faces and generatrix. The most promising for obtaining such images is the shadow projection method in combination with automated tools for pattern recognition. Implementation of this method is based on using a device to obtain the image of shadow projection and a device for the registration of this image and its digitizing. For this purpose, a specialized software is employed developed to recognize a pattern of packing in the image, and to build its 3D model.

In the present paper we consider the method of shadow projection [9] in combination with automated methods of pattern recognition that allow obtaining three-dimensional models of packings [10, 11]. Publications [12–15] address the implementation of this method. They apply the following methods of research: analysis of measurement errors and geometrical optics.

In order to control defects in the shape of packing by the shadow projection method, it is required to determine the height of profile  $H$  in the controlled area of packing in the normal section (Fig. 1). However, when using the section shadow projection method, camera captures the height of the shadow that corresponds to height of profile  $h$  in some inclined section. Directly proportional dependence exists between these magnitudes

$$H = Mh, \quad (1)$$

where  $M$  is the scale of profile conversion.

In [9], it is shown that the formation of an image in the space of objects of the registering camera occurs differently, depending on whether the examined surface reflects or

scatters light. A winding body surface is formed by textile threads and fibers included in their composition and, therefore, it represents the surface that scatters light.

Let us define the of profile scale conversion and the position of profile image in the space of objects in the recording camera for the surfaces that scatter light.

Fig. 1 shows a step of height  $H$ , formed by scattering surfaces  $A$  and  $B$ . Points  $M_A$  and  $M_V$  are on the border of intermediate image edge of shutter  $S$  projected onto these surfaces.  $O_1-O_1$  and  $O_2-O_2$  are the optical axes of illuminator and registering camera.  $L_0$  is the distance of object point  $O$  to the middle line of the profile,  $P_1$  is the object plane of the recording camera.

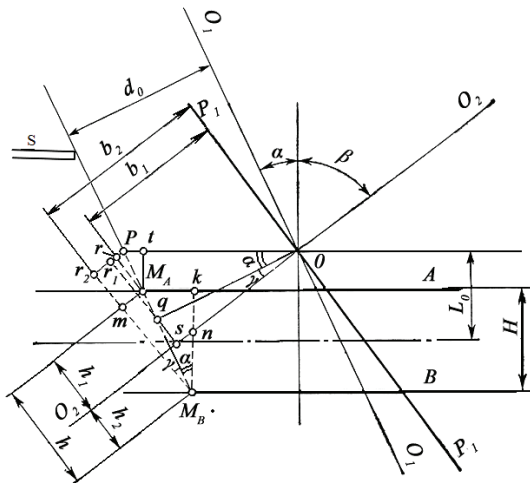


Fig. 1. Position in the space of objects in the profile observation camera, formed by the projection of edge of shutter onto the step surface

Distances from points  $M_A$  and  $M_B$  to the optical axis  $O_2-O_2$  of the camera are denoted as  $h_1$  and  $h_2$ , and the distances from these points to the object plane  $P$  through  $b_1$  and  $b_2$ . Define the height of profile  $H$ , registered by the camera. From triangle  $kM_A M_B$ , we obtain

$$M_A M_B = \frac{H}{\cos \alpha},$$

and from triangle  $mM_B M_A$

$$h = m M_B = M_A M_B \cos \gamma$$

that is

$$h = H \frac{\cos \gamma}{\cos \alpha}. \tag{2}$$

Assume that angle

$$\angle n M_B = \beta,$$

then angle

$$\angle n M_B m = 90^\circ - \beta.$$

Fig. 1 shows

$$\gamma = \angle m M_B n - \alpha = 90^\circ - \beta - \alpha.$$

With regard to the latter

$$h = H \frac{\sin(\alpha + \beta)}{\cos \alpha}, \tag{3}$$

in other words, the scale of conversion without regard to the optical and digital magnification of the camera is

$$M = \frac{H}{h} = \frac{\sin(\alpha + \beta)}{\cos \alpha}. \tag{4}$$

Position of the image of shadow in the camera focus is determined by the magnitudes  $h_1$  and  $h_2$ . They depend considerably on the position of the shutter, which is defined by magnitude  $d_0$  and position of object point  $O$ , which is determined by the size  $L_0$ . Fig. 1 shows that

$$h_1 = sq + qr_1 - M_A r, \tag{5}$$

$$h_2 = M_B r_2 - sq - qr_1. \tag{6}$$

Find the magnitudes of sections included in (5) and (6).

$$M_A t = L_0 - \frac{H}{2}. \tag{7}$$

From triangle  $M_A p t$

$$M_A p = \left( L_0 - \frac{H}{2} \right) \frac{1}{\cos \alpha}. \tag{8}$$

From triangle  $M_A r p$

$$M_A r = \left( L_0 - \frac{H}{2} \right) \frac{\cos \gamma}{\cos \alpha} = \left( L_0 - \frac{H}{2} \right) \frac{\sin(\alpha + \beta)}{\cos \alpha}. \tag{9}$$

By analogy, we obtain expression to determine

$$M_B r_2 = \left( L_0 + \frac{H}{2} \right) \frac{\sin(\alpha + \beta)}{\cos \alpha}. \tag{10}$$

From triangle  $q O p$

$$pq = d_0 \operatorname{tg} \alpha, \tag{11}$$

while  $qr_1 = pq \cos \gamma = pq \sin(\alpha + \beta)$ . Substituting (11) in the latter expression, we obtain

$$qr_1 = d_0 \operatorname{tg} \alpha \sin(\alpha + \beta). \tag{12}$$

From triangle  $q s O$

$$qs = d_0 \sin \gamma = d_0 \cos(\alpha + \beta). \tag{13}$$

Substituting the values of sections from (8), (12) and (13) into (5), we obtain expression for computing  $h_1$

$$h_1 = d_0 \cos(\alpha + \beta) + d_0 \operatorname{tg} \alpha \sin(\alpha + \beta) - \left( L_0 - \frac{H}{2} \right) \frac{\sin(\alpha + \beta)}{\cos \alpha}. \tag{14}$$

Similarly, after substituting (10), (12) and (13) into (6), we receive

$$h_2 = \left( L_0 + \frac{H}{2} \right) \frac{\sin(\alpha + \beta)}{\cos \alpha} - d_0 \operatorname{tg} \alpha \sin(\alpha + \beta) - d_0 \cos(\alpha + \beta). \quad (15)$$

Magnitude  $b = b_2 - b_1$  determines the required magnitude of depth of field of the recording camera. Sections  $b$  and  $h$  are cathets in triangle  $mM_B M_A$ , which is why with regard to (3), it is possible to write

$$b = H \frac{\cos(\alpha + \beta)}{\cos \alpha}. \quad (16)$$

Depth of field of the lenses used in digital cameras when taking images from a distance of 0.4 m is approximately 10 cm, that is much larger than magnitude  $b$ . Thus, obtaining a sharp image is always ensured.

It follows from formulas (3) and (16) that the scale of conversion depends on the angle of projection  $\alpha$  and angle  $\alpha + \beta$  between the optical axes of illuminator and camera. At constant value of observation angle  $\beta$ , the conversion scale increases with increasing angle of projection  $\alpha$ . If angles of projection  $\alpha$  and of observation  $\beta$  are not equal, then the scale of profile conversion and sections  $h_1$  and  $h_2$ , defining the position of profile in the camera's field of view, are different even at  $L_0 = 0$  and  $d_0 = 0$ .

In the device for obtaining the initial image  $\beta = 0$ , considering this, formulas (3), (14) and (15) will be rewritten in the form

$$h = H \operatorname{tg} \alpha, \quad (17)$$

$$h_1 = d_0 \cos \alpha + d_0 \operatorname{tg} \alpha \sin \alpha - \left( L_0 - \frac{H}{2} \right) \operatorname{tg} \alpha. \quad (18)$$

$$h_2 = \left( L_0 + \frac{H}{2} \right) \operatorname{tg} \alpha - d_0 \operatorname{tg} \alpha \sin \alpha - d_0 \cos \alpha. \quad (19)$$

Let us consider the case when the normal to surface is not in the plane that crosses the optical axes of camera and illuminator but is deflected through angle  $\varphi$  (Fig. 2). In the camera's field of view, the image of surface in the form of a border between light and shadow will be tilted relative to the horizontal at angle  $\varphi$ . Fig. 2 shows the image of border between light and shadow in the object plane of the recording camera, formed by scattering surfaces A and B, which form a step of height  $H$ . The optical axes of illuminator and camera are in the plane  $NN$ . After turning planes A and B by angle  $\varphi$ , they will take positions  $A'A$  and  $B'$ , in this case, the angle between the normal to surfaces  $A'$  and  $B'$  and the plane  $NN$  will also be equal to  $\varphi$ .

The height of the step now depends on the width of the observed object; in our case, on the width of a bobbin or the winding thickness. We shall denote this magnitude as  $L$ . Points  $M_A$  and  $M_B$ , positioned on the edges of the observed image of a shadow prior to the rotation of an object, will shift to points  $M'_A$  and  $M'_B$ , respectively. The height of the

observed shadows will reach  $H'$ . When turning the normal to surfaces A and B at angle  $\varphi$ , point  $b$  on the border of the shadow will pass to point  $c$  along a circle that has radius  $bd = cd$ . Angle  $bdc = \varphi$ , and angle

$$bda = \arcsin \frac{H}{\sqrt{H^2 + L^2}}. \quad (20)$$

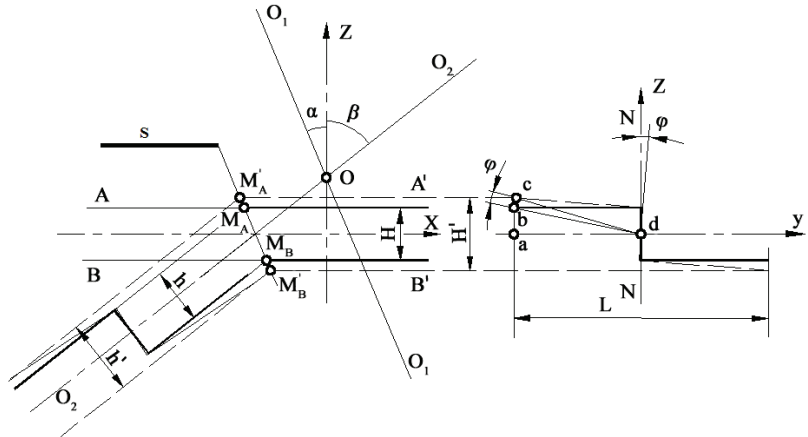


Fig. 2. Position in the space of objects in the profile observation camera formed by the projection of edge of shutter onto the step surface, tilted to the plane  $O_1 O_2$

The distance from point  $c$  to the  $X$  axis can be calculated by formula

$$\frac{H'}{2} = bd \sin(\operatorname{adc}).$$

Considering that angle

$$\operatorname{adc} = bda + bdc,$$

and

$$bd = \sqrt{H^2 + L^2},$$

after obvious transformations, we finally obtain

$$H' = \sqrt{H^2 + L^2} \sin \left( \varphi + \arcsin \frac{H}{\sqrt{H^2 + L^2}} \right). \quad (21)$$

Appropriately, from  $h$  to  $h'$ , the observed magnitude of the shadow will change. Since angles  $\alpha$  and  $\beta$  are unchanged, then the magnitude  $H'$  can be converted to  $h'$  by formula, similar to (3)

$$h' = H' \frac{\sin(\alpha + \beta)}{\cos \alpha}. \quad (22)$$

Substituting value  $H'$  from (21), we finally receive

$$h' = \sqrt{H^2 + L^2} \sin \left( \varphi + \arcsin \frac{H}{\sqrt{H^2 + L^2}} \right) \frac{\sin(\alpha + \beta)}{\cos \alpha}. \quad (23)$$

The formula for computing the scale of conversion will take the form

$$M = \frac{h'}{H} = \sqrt{1 + \left(\frac{L}{H}\right)^2} \sin \left( \varphi + \arcsin \frac{1}{\sqrt{1 + \left(\frac{L}{H}\right)^2}} \right) \frac{\sin(\alpha + \beta)}{\cos \alpha}. \quad (24)$$

The resulting formula allows us to run an analysis of errors when controlling the surface profile of a bobbin by the shadow projection method. The main sources of systematic errors in the selected measurement method are: accuracy of scale of conversion and an error caused by the curvature in the image of shadow edge.

### 5. Discussion of the results of examining the process of converting the image of a shadows on the packing into a digitized image

The paper presents results of examining the conversion process of an image of shadow on the packing into a digitized image. Based on these results, obtained in real time when unwinding the packing, it appears possible to trace the existence of defects in shape over the entire winding thickness. The indicated defects are usually the result of design deficiencies in a bobbin winder or violations in the terms of technological pro-

cess. Thus, the proposed methodology, on the one hand, makes it possible to find design drawbacks in the mechanism at the stage of its testing and to resolve them in a timely manner. On the other hand, it provides for the possibility to make recommendations on the operation of a bobbin winder, precluding the formation of defective winding. Present research is the continuation of our previous studies with the results published in [10–15]. Further work on improving the method of control of textile packings should be aimed at improving the software for processing the results of initial measurements.

### 7. Conclusions

1. We received dependences for determining the scale of conversion when controlling the shape of a bobbin by the shadow projection method on the design parameters of the device. They take into account the slope of the controlled surface to the plane, formed by the optical axes of illuminator and a photographic sensor that is a specific requirement when controlling the shape of textile packings.

2. It is shown that the scale of conversion is affected not only by the angles between the normal to the bobbin's surface and the optical axes of illuminator and a photographic sensor, but also by the width of the controlled bobbin.

3. Received expressions make it possible to reasonably consider the choice of design parameters of a device to control the shape of textile packings.

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