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Computer Modelling of Yarn Winding on Conical Bobbins

Računalniško modeliranje navijanja preje na stožčaste navitke

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Abstract

The article presents the results of the computer modelling of yarn winding on conical bobbins based on the analytical method of constructing tubular-shaped surfaces as a partial case of channel surfaces using the vector algebra apparatus. It is stated that the guide line takes the shape of a conical spiral line along which the forming moves (in the form of a circle with a diameter equal to the average diameter of the yarn), and is set using the moving Frenet basis. The obtained mathematical models facilitate the building, in MathCAD 3D visualization graphics, of a tubular-shaped surface, which represents the layers of yarn winding on a conical cartridge, and the reinforced yarn, which comprise the core component and the wrapping component, as well as the determination of both the lengths of individual layers of winding and the total length of winding (not including the transition sections). Well-known methods of forming geometric objects and computer modelling were also used in the work. The theoretical studies are based on the basic principles of textile production technology.

Keywords: yarn, rewind, bobbin, tubular-shaped surfaces, Frenet basis, computer modelling

Izvleček

V članku so predstavljeni rezultati računalniškega modeliranja navijanja preje na stožčaste navitke, kjer so bile kot primer žlebičastih površin z uporabo analitične metode vektorske algebre konstruirane cevaste površine. Vodilna linija ima obliko stožčaste spirale, vzdolž katere poteka oblikovanje (v obliki kroga s premerom, ki je enak povprečnemu premeru preje) in se nastavi s pomočjo gibljive Frenetove baze. Dobljeni matematični modeli omogočajo vizualizacijo cevaste površine s pomočjo grafičnega orodja MathCad 3D, tj. plasti preje, navitih na cevko stožčaste oblike, ojačitvene preje iz jedra in ovojne komponente in določanje dolžine posameznih plasti navitja kot tudi celotne dolžine navitja (brez prehodnih odsekov). Pri tem so bile uporabljene znane metode oblikovanja geometrijskih objektov in računalniškega modeliranja. Teoretične študije temeljijo na osnovnih principih tehnologije za izdelavo tekstilij.

Ključne besede: preja, navijanje preje, stožčasti navitek, Frenetova osnova, računalniško modeliranje



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1 Introduction

One of the main tasks of the textile industry is the development of new textile technologies that meet modern specific production requirements. Such technologies include the technology of winding during the formation of specialized winding packages, for example, winding threads and thread-like materials on cartridges, coils, etc.

Today, winding has turned from a separate technological operation of yarn preparation into an independent technological process of obtaining an original product. The process of forming winding packages, which are original products, requires theoretical research, in particular, using the computer modelling of packaging and the computer modelling of the winding mechanism [1].

The need to use computer modelling is explained by requirements to shorten the time to develop technologies and mechanisms of technological machines, and to increase the accuracy of research results and the efficiency of researchers' work.

Modern information technologies are tools used for creating simulated computer models that ensure automated production control for yarn rewinding [2], which is evidenced by the researchers' interest in the use of modern information technologies, and whose scientific works are devoted to the computer modelling of packaging and winding mechanism using various methods. In particular, the computer model of yarn winding described in research [3] is implemented based on Ls-Dyan software using the finite element modelling of the yarn winding process to analyse the change in yarn tension during and after winding.

To study the change in the tension of cotton yarn during the winding process, a finite-element model of yarn based on three-dimensional beam elements using the Abaqus dynamic explicit software is proposed in the paper [4]. In the work [5], the 3DS MAX 2010 software was chosen to simulate the geometry of yarn. The research [6] describes methods for modelling yarn structures using three-dimensional

computer graphics, and results in a mathematical model that reproduces yarn (computer visualization of yarn). The work [7] describes a computer-integrated environment for the simulation of the yarn winding process that includes design, production and quality control, which resulted in the development of yarn winding machines.

Therefore, the development of computer modelling methods and the use of modern applied computer programs for this purpose are timely tasks.

The results of this research can contribute to the development of modern information technologies for the modelling of textile processes based on its use as a tool for researching the analytical method of constructing tubular-shaped surfaces using the vector algebra apparatus and through its implementation in the MathCAD CAE program.

The tasks of the research were:

- to create mathematical models based on vector algebra that describe yarn packaging;
- to create a software code based on the obtained mathematical models; and
- to make a computer modelling of yarn packaging with the construction of visualization graphs in the MathCAD application program.

2 Research methodology

Technology and equipment for yarn rewinding are constantly being improved, as evidenced by recent active research on these issues, in particular, works on the development of winding machines [1, 8–10] and research on winding processes [11–18].

When yarn is prepared for knitting on knitting machines, it is rewound from incoming packages onto a conical cartridges using a cross-winding process, resulting in cross-wound conical bobbins.

Since the size of the yarn in length is much larger than the size of the cross-section, the cross-section of the yarn is assumed to be circular, disregarding the change in cross-sectional area during winding.

For the computer modelling of the turns of yarn

winding, the expression [19] can be used, which determines the location of the points of the surface (described by the radius-vector S_1) in MathCAD (Figure 1) that forms the turns of yarn winding

$$S_1(u, v) = P_1(u) + l_2 \cdot \cos(v) \cdot \nu(P_1, u) + l_2 \cdot \sin(v) \cdot \beta(P_1, u) \tag{1}$$

where $P_1(u)$ represents a radius-vector that depends on the angular parameter u and determines the coordinates of the points of the conical spiral guide line; the hodograph of the radius-vector $P_1(u)$ represents the axial line of the tubular-shaped surface; u represents the rotation angle of the projection of the radius-vector $P_1(u)$ on the horizontal plane, which is counted from the abscissa axis; $l_2 = \frac{d_{fil}}{2}$ represents the length of the vector $P_2(v)$, which determines the coordinates of the points of forming in the form of

along the conical spiral guide line (described by the radius-vector P_1), by which the forming moves (in the form of a circle with a diameter equal to the average diameter of the yarn d_{fil}):

a circle with a diameter d_{fil} ; v represents a parameter that determines the rotation angle of the radius-vector with a length equal to d_{fil} ; $\nu(P_1, u)$ represents the component (orth) of the normal vector of the Frenet basis; and $\beta(P_1, u)$ represents the component (orth) of the binormal vector of the Frenet basis.

The angle v is counted from the vector ν towards the vector β while rotating around the orth of the tangent vector t to the hodograph of the radius-vector $P_1(u)$ counterclockwise.

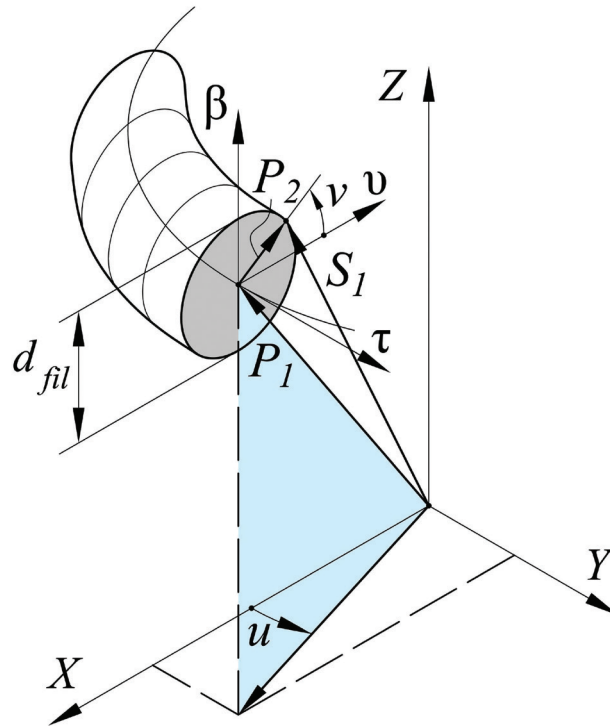


Figure 1: Calculation scheme for determining the location of the points of the surface in MathCAD that forms the turns of yarn winding

The average diameter of the yarn d_{fil} can be determined by the expression:

$$d_{fil} = \sqrt{\frac{T \cdot 10^{-3}}{\pi \cdot \rho_1}} + \sqrt{\frac{T \cdot 10^{-3}}{\pi \cdot \rho_2}} \tag{2}$$

where T represents the linear density of yarn in g/km, ρ_1 represents the average density of yarn in g/m³ and ρ_2 represents the density of fibre in g/m³.

To determine the orthos of the Frenet basis $\tau(PL_1, u)$, $\nu(PL_1, u)$ and $\beta(PL_1, u)$, it is possible to use the expressions from differential geometry [20], which will be written in the program code in

$$r'(r, u) = \begin{bmatrix} \frac{d}{du}(r(u)_x) \\ \frac{d}{du}(r(u)_y) \\ \frac{d}{du}(r(u)_z) \end{bmatrix}; \quad r''(r, u) = \begin{bmatrix} \frac{d^2}{du^2}(r(u)_x) \\ \frac{d^2}{du^2}(r(u)_y) \\ \frac{d^2}{du^2}(r(u)_z) \end{bmatrix} \tag{3}$$

$$\tau(r, u) = \frac{r'(r, u)}{|r'(r, u)|}; \quad \beta(r, u) = \frac{r'(r, u) \times r''(r, u)}{|r'(r, u) \times r''(r, u)|}; \quad \nu(r, u) = \beta(r, u) \times \tau(r, u) \tag{4}$$

The body of winding is a conical surface that is formed when the yarn is wound on a conical cartridge. Let's consider the process of winding, during which the conical cartridge carries out only a rotation movement, as a result of which the ends of the bobbin do not have a spherical, but rather a flat surface, as is the case when the conical cartridge carries out a rotational movement and a translational movement simultaneously along the axis of rotation towards the end with a larger diameter. To model the surface of the conical cartridge, the radii R_1 of the larger and r_1 of its smaller ends, located at the distance of the winding height h_1 , need to be entered. The number of turns of winding that fit at the height h_1 is designated as n_1 . Taking a discrete variable n that specifies the number of the winding layer:

$$n = n_0 - n_{\max} \tag{5}$$

where n_0 and n_{\max} represent, respectively, the numbers of the initial and final layers with a pitch equal to one.

3 Results

To model conical surfaces, tubular-shaped surfaces and conical spiral lines, the matrix of the vector lying in the XY plane that rotates around the Z axis can be used:

$$T_z(u) = \begin{bmatrix} \cos(u) & -\sin(u) & 0 \\ \sin(u) & \cos(u) & 0 \\ 0 & 0 & 1 \end{bmatrix}; \quad M_1(u, v) = \begin{bmatrix} R_1 - v \cdot \frac{R_1 - r_1}{h_1} \\ 0 \\ v \end{bmatrix} \tag{6}$$

where $M_1(u, v)$ represents the equation of the cone (conical cartridge) in parametric form.

accordance with MathCAD requirements using own functions (user functions) to calculate the derivatives of the radius-vector r , which is given in a parametric form:

To visualize the conical cartridge on 3D graphics in MathCAD (Figure 2), the following expression can be used:

$$Plot_1 = CreateMesh(M_1, 0, 2\pi, 0, h_1, 36, 10) \tag{7}$$

where the u parameter is in the interval $0 \leq u \leq 2\pi$ (the number of grid lines is 36); and the v parameter is in the interval $0 \leq v \leq h_1$ (the number of grid lines is 10).

Let's present the equation of the line of yarn winding on a tubular-shaped surface in a parametric form:

$$P_1(u, n) = T_z(u) \cdot \begin{bmatrix} R_1 + \frac{d_{fil}}{2} + (n-1) \cdot d_{fil} - \frac{p_1 \cdot u}{2 \cdot \pi} \cdot \frac{R_1 - r_1}{h_1} \\ 0 \\ \frac{p_1 \cdot u}{2 \cdot \pi} \end{bmatrix} \tag{8}$$

where p_1 represents the pitch of the turn of winding; $p_1 = h_1/n_1$.

During the reverse movement of the thread guide (thread unwinder), the argument of the rotation matrix T_z in the expression (8) will be the angle “ $-u$ ”, i.e., $T_z(-u)$.

In addition to the u angle, the number of the layer n is entered as a parameter in the expression (8), which facilitates the modelling of the corresponding layer on the visualization graphics in MathCAD and the determination of both the length of each of the layers and the sum of the lengths of the layers, as well as the total length of winding.

To calculate the length of winding layers, we introduce our own function, which is based on the well-known expression for determining the length of a spatial curve given in a parametric form [20]:

$$Length_1(r, \alpha_1, \alpha_2, n) = \int_{\alpha_1}^{\alpha_2} \sqrt{\left(\frac{d}{du}(r(u, n)_x)\right)^2 + \left(\frac{d}{du}(r(u, n)_y)\right)^2 + \left(\frac{d}{du}(r(u, n)_z)\right)^2} du \quad (9).$$

The expression (9) can be used to determine the length function of a separate layer of winding in MathCAD, depending on the layer number n :

$$L_1(n) = Length_1(P_1, 0, 2\pi \cdot n_1, n) \quad (10).$$

The total length of winding is determined by the expression:

$$L_{SUM} = \sum_n L_1(n) \quad (11).$$

In the expression (10) the length of n layer with n_1 turns is calculated in the interval $0 \leq \alpha \leq 2\pi n_1$.

To simulate the first layer of winding on a 3D graph of the visualization in MathCAD, the following expression can be used:

$$PL_1(u) = P_1(u, 1) \quad (12).$$

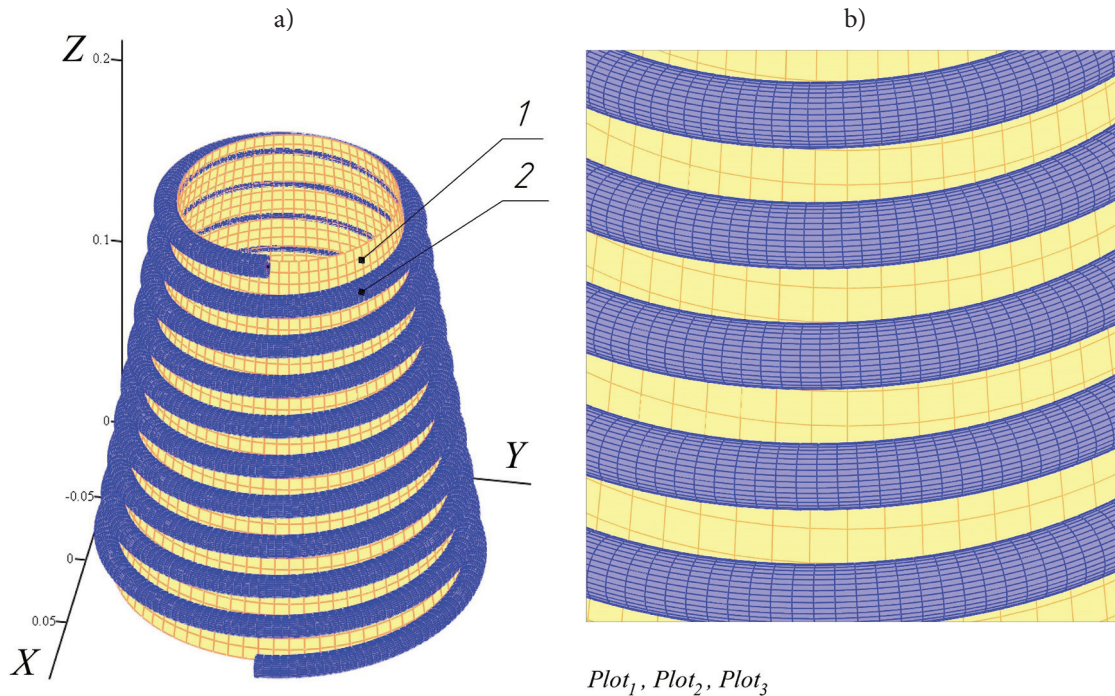
Any layer can be entered according to the expression (12), replacing the index "1" and the value of the parameter "1" in the entry $PL_1(u, 1)$ with the number of the desired layer.

The graph of visualization of the middle (axial) line of the first layer, as well as the graph of the tubular-shaped surface, which is the yarn, are built using the following expressions in MathCAD:

$$Plot_2 = CreateSpace(PL_1, 0, 2\pi \cdot n_1, 36 \cdot n_1) \quad (13)$$

$$Plot_3 = CreateMesh(S_1, 0, 2\pi \cdot n_1, 0, 2\pi, 36 \cdot n_1, 36) \quad (14).$$

Similar to the expressions (13) and (14), it is possible to write expressions for building the graphs of other layers of winding.



$Plot_1, Plot_2, Plot_3$

Figure 2: Graphics of visualization of the first layer of winding of yarn on a conical cartridge: a) a conical cartridge with yarn; b) a yarn in the form of tubular-shaped surface

Using the expression (1), it is possible to run the computer modelling of reinforced yarn, which comprises the core component 2 (Figure 3) and the wrapping component 3. It can therefore be rewritten as follows:

$$S_2(u, v) = P_4(u) + l_3 \cdot \cos(v) \cdot v(P_4, u) + l_3 \cdot \sin(v) \cdot \beta(P_4, u) \quad (15)$$

where $P_4(u)$ represents the radius-vector that determines the coordinates of the points of the spiral guide line (the axial line of the wrapping component in the yarn), which is wound on the surface of the yarn $S_1(u, v)$ considering the equidistant distance l_3 between the core and the wrapping components, which is equal to half of the diameter d_{arm} of the wrapping component.

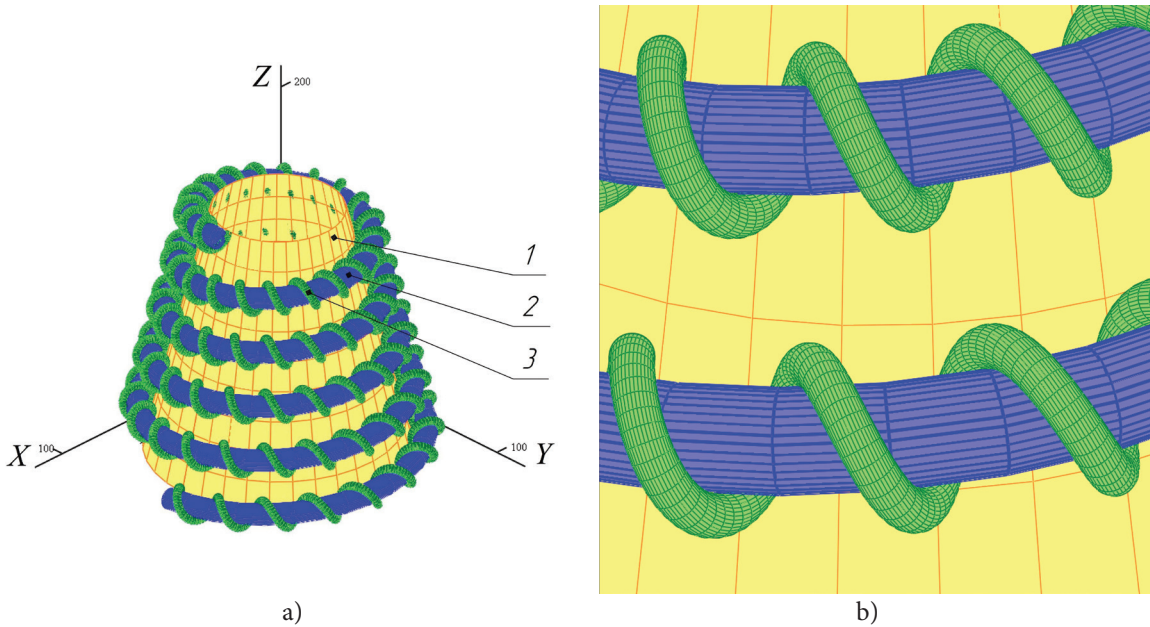


Figure 3: The graphics of visualization of the first layer of winding of reinforced yarn on a conical cartridge: a) a conical cartridge with reinforced yarn; b) a reinforced yarn in the form of tubular-shaped surface of the core component 2 and the wrapping component 3

The radius-vector $P_4(u)$ can be determined from the expression (for the first layer of winding):

$$P_4(u) = P_3(u) + (l_2 + l_3) \cdot \cos(u \cdot n_{arm}) \cdot v(P_3, u) + (l_2 + l_3) \cdot \sin(u \cdot n_{arm}) \cdot \beta(P_3, u) \quad (16)$$

where $P_3(u)$ represents the radius-vector that determines the coordinates of the points of the spiral guide line of the wrapping component:

$$P_3(u) = T_z(u) \cdot \begin{bmatrix} R_1 + \frac{d_{fil}}{2} + \frac{d_{arm}}{2} + (n-1) \cdot (d_{fil} + 2 \cdot d_{arm}) - \frac{P_1 \cdot u}{2 \cdot \pi} \cdot \frac{R_1 - r_1}{h_1} \\ 0 \\ \frac{P_1 \cdot u}{2 \cdot \pi} \end{bmatrix} \quad (17)$$

n_{arm} represents the number of turns of the wrapping component winding, which are placed on the length of one turn of the line of the core component

$P_3(u)$; and l_3 represents the radius (the half of the average diameter) of the wrapping component.

4 Conclusion

The computer modelling of packaging in the form of a bobbin with a cross winding of yarn is one of the tools used for studying and optimizing processes in the textile industry. The obtained mathematical models and program code in MathCAD can be useful when studying the influence of various factors on the quality of yarn winding. The use of computer modelling allows the user to virtually create a bobbin with a cross winding of yarn, reproducing the position of the turns of yarn winding, and also provides an opportunity to experiment with various parameters that can affect the quality of winding. This enables virtual testing and process optimization without the need for physical experiments, which helps to reduce costs, and improve the quality and efficiency of production in the textile industry. The task of modelling transition sections of winding layers (splice-pieces) remains for the further research.

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