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Theoretical Research of Mechanics of Yarns in Assembly Winding Machines

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Abstract

In practice, in most cases, the geometric dimensions of the cylindrical yarn generated in the assembly winding machine are also an important controllable parameter in ensuring the quality of the twisted yarns and achieving optimal performance of the equipment. However, on the other hand, it is no secret that in justifying the geometric dimensions of the winding, it is necessary to take into account both the values of tension and relative deformation of individual and paired yarns. Therefore, in this theoretical study, the change in the values of tension and relative deformation of the yarns along the width of the winding was studied.

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1 Introduction

It is known from the studies that over time, the current distance from the yarn rotor to the winding surface of the bobbin varies, the winding angle of the paired yarns changes, and the resulting value of the paired yarn tension fluctuates, random or systematic Factors such as the linear density of individual yarns vary on a random basis have a direct effect on the quality of the twisted yarn. To theoretically study the tension of the yarns to be joined in the section from the yarn to the cylindrical coil and their deformation properties in the stationary mode (Chapman, 1971), we express the assembly winding machine as in the following scheme (Figure 1):

As can be seen in the upper part of the machine, i.e. in the winding part of the paired yarns, the following forces act on the joining yarn:

V_{ps} - pulled speed of the yarn from the spool, V_w -speed of winding the yarn in the direction perpendicular to the spool, V_{rax} -speeding speed of the yarn in the horizontal direction.

From the diagram of the forces acting on the yarn above, we determine the current length of the yarn in the distance from the tensioning device to the winding device yarn guide as follows:

$$AO = l_1\sqrt{1+tg^2 a} \qquad (1)$$

Here:

l_1 = the distance from the tensioning device to the path of movement of the yarn guide;
α = the current angle of inclination of the yarn between the tensioner and the winding device.

When analyzing the yarn tension in existing assembly winding machines, it should be noted that the yarn is driven from the yarn conductor 1 to the tensioner device pair (2-3), and the yarn is leading from the tensioning device pair 2-3 to the winding device guide 4. From a dynamic point of view, it is possible to search for the parameters of the tension determination equation depending on the yarn as a driven link between the tensioning device pair 2-3 and winding device guide 4 and the yarn as a leading link in the distance from the winding device guide 4 to the cylindrical coil surface (Carslaw & Ropkins, 2012; Saura & Torne, 2009).

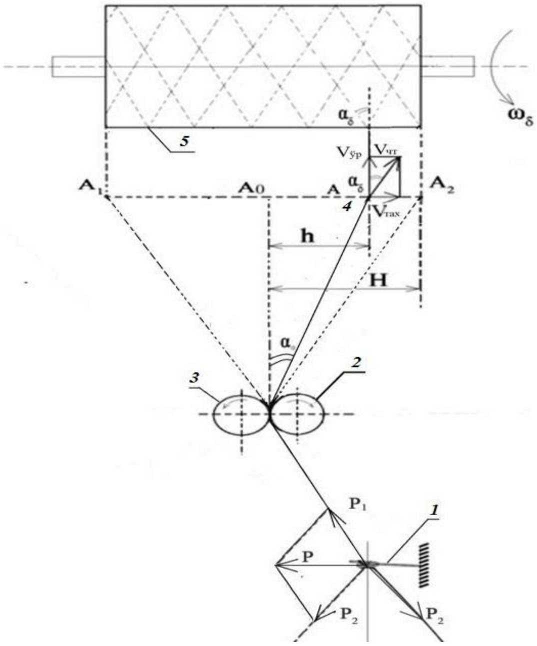

Figure 1. Forces acting on the yarn between the winding drum of the tensioning device
1-yarn conductor, 2-3 yarn tensioning device (pendulum), 4-yarn guide, 5-cylindrical coil

The following kinematic conditions are set for the winding device guide 4 and the cylindrical coil winding the paired yarns (2):

$$tg\alpha_{б} = \frac{V_{\text{тах}}}{(\omega_{б} r_{б})} \quad (2)$$

Here;

$\alpha_{б}$ = the angle of winding the yarn on the spool;

$\omega_{б}$ = angular velocity of rotation of the roller (cylindrical coil);

$r_{б}$ = current radius of the package;

$V_{\text{тах}}$ = the speed of the yarn in the horizontal direction.

2 Materials and Methods

The principle of operation of the mechanism of winding the yarn on the spool (coil)

When two or more individual yarns are pulled from the coils mounted on the lower part of the machine using a tensioner (pendulum) 4, a cylindrical coil is formed by wrapping the paper cartridges as a result of the horizontal-reverse movement of the yarn guide (Kärrholm et al., 1955; Tozhimirzaev et al., 2020; Parpiyev & Meliboyev, 2020). The results show that over time, the current distance from the yarn guide to the winding surface of the coil varies, the winding angle of the paired yarns changes and the resulting value of the paired yarn tension fluctuates, random or systematic Factors such as the linear density of individual yarns vary on a random basis has a direct effect on the quality of the twisted yarn (Zambrano et al., 2017).

Therefore, the selection and justification of the main technological parameters of the assembly winding machine, such as the correct selection of loads in a special tensioning device, the tension of individual and paired yarns, winding speed, and the basic dimensions of the cylindrical winding is a practical process in ensuring the stability of this technological process and consequently improving the quality of twisted yarn (Meliboev & Parpiev, 2020; Meliboev et al., 2020; Meliboev et al., 2020). When setting up the machine, it is important to wrap the yarn in the required density on the spool first. Insufficient wrapping density on the one hand affects the productivity of the twisting machine by reducing the mass of the wrapper, on the other hand, it can lead to uncontrolled movement of yarn layers during the pulling stage in the twisting machine due to non-tight wrapping of yarn layers on the spool.

Conversely, an excessive increase in packing density can also lead to various adverse events. This process can be controlled by changing the loads placed on the control groove in the yarn tension adjustment device on modern assembly winding machines. In this case, of course, if the tensile force of the yarn on the yarn tensioning device (pendulum) 4 is less than the tensile force of the yarn, the thread tensioner (pendulum) 4 will slip through and negatively affect the winding on the coil 6. Therefore, in this section, the forces of yarn tension and deformation processes in yarns are theoretically studied (Amirante et al., 2006; Vanini et al., 2014).

The tension of the yarn between a pair of tensioning devices and a cylindrical winding drum is due to its forward motion at a certain speed and the friction generated by the tensioning device. The importance of the technologically generated yarn tension is enormous, as its deviation from the acceptable value can lead to negative consequences such as a decrease in yarn quality, frequent breakage of individual yarns, or distortion of the winding shape (Abdalla et al., 2007; O'Brien, 1998).

Theoretical study of the calculation of yarn tension between the output roller and the spool

Aiming to achieve a theoretical study of the factors influencing the tension by theoretically calculating the yarn tension between the spinning roller and the spool, as shown in the figure, after joining a single yarn at the yarn conductor 2, the yarn tensioning device (pendulum) 3-4 pairs are passed at certain friction through the holes in the winder 5 to the winding mechanism coil 6. Depending on the tensile strength of the tensioning device 3 (pendulum), the tension of the yarn relative to the tension before and after the roller may slip between the yarn and the roller. This in turn causes the yarn to be wound on the spool at an uneven speed (Vasarhelyi & Ván, 2006; Song & Hwang, 2004). To prevent this, a compression compensator roller 4 is installed. In section OA (Fig. 2.1) the yarn moves longitudinally. There is no break in the yarn during this interval. This is because the kinematic effect of wave motion creates a yarn effect as a result of elongation deformation along the yarn. This happens when the speed at which the yarn moves forward is equal to the speed at which sound propagates along the yarn (Parpiev & Meliboev, 2020a; Parpiev & Meliboev, 2020b; Parpiev & Meliboev, 2020c). The frequency of the longitudinal specific vibration of the yarn reaches a large value and is also greater than the frequency of exposure to the external environment. Therefore, the determination of the longitudinal deformation of the yarn takes the form of a quasi-static problem. In this case, the tensile strength of the yarn in the interval under study is determined by the following formula (3) (Korabayev et al., 2018).

$$P\left(t\right)=P_0(t)+Tx\frac{\partial v_0}{\partial t}-\frac{1}{2}\cdot T\cdot \omega_e^2(t)x^2-\int_0^x F_1(x_1t)dt \tag{3}$$

$\mathrm{P(t) = P_o(t) + Tx\frac{\partial v_0}{\partial t} - \frac{1}{2} \cdot T \cdot \omega_e^2(t)x^2 - \int_0^x F_1(x,t)dt}$

Where: $P(t)$ is the tensile force generated in the yarn; $P_0(t)$- Longitudinal tensile force generated in the thread at point O (Fig. 1); the second and third terms are the forces of inertia created by the mass of yarn as a result of longitudinal, rotational motion; $F_1(x_1t)$- force generated by external force factors. If we want to simplify the issue a bit, we can ignore the forces of external influence.

From the general formula of tension (2) given above, the force $P_0=P_0(t)$ is the tensile strength of the yarn formed in the yarn in the section OA, and this tensile strength is determined by the relative elongation deformation of the yarn in that section.

We denote ℓ is the length of the yarn in the section OA and ε_1 is the relative deformation of the yarn entering the section OA, and ε is the relative deformation of the yarn in the section OA and the corresponding velocities v_1 and v_2.

In this case, we determine the relative longitudinal deformation of the yarn in the section OA by the following formula (4);

$$\varepsilon=-1+\frac{v}{v_1}\cdot(1+\varepsilon_1)[1+\beta^2\Phi^2(t)] \tag{4}$$

Where: minimum longitudinal deformation: $\varepsilon_1=\frac{P_4}{A_1}$

$$\varepsilon_{\min}=-1+\frac{v}{v_1}(1+\varepsilon_1)$$

Relative gain deformation is $\Delta\varepsilon=\frac{1}{2}\left(\frac{H}{\ell_1}\right)^2\left(\frac{v}{v_1}\right)(1+\varepsilon_1)$.

Hence the longitudinal relative deformation is equal to the following expression;

$$\varepsilon=\varepsilon_{\min}+\Delta\varepsilon\Phi^2(\mathrm{t}) \tag{5}$$

Here:

H = is the sheer amplitude of the eye of the yarn conductor of the yarn winder;

$\Phi(\mathrm{t})$ = is the oscillation function of the A-link, i.e., the eye of the yarn conductor of the yarn winder;

If we assume that $\Phi(\mathrm{t})=\sin\mathrm{P}_{2\mathrm{A}}t$ its change interval is equal to $-1\leq\Phi(\mathrm{t})\leq1$.

If we assume that the time is in the following interval $0 \le t \le t_A$, that is, link A is equal to the frequency of vibration of the string $\mathrm{P}_{2A} = 2\pi f_{2A}$ and the period of oscillation $f_{2A} = \dfrac{1}{t_A}$. t_A - the time spent on the biggest deviation of the link A. The coefficient β^2 in the third term of equation (5) is calculated as follows:

$$\beta^2 = \frac{1}{2}\left(\frac{H}{\ell_1}\right)^2; \tag{6}$$

Taking into account the above, the velocities of the yarn entering and leaving the OA section are determined by the following formulas, respectively:

$$\nu = \nu(t) = \eta_2 V_{ўр}\sqrt{1+tg^2\alpha_б} \tag{7}$$

$$\nu_1 = \eta_1 \cdot V_{ch} \tag{8}$$

Here, η_1, η_2 are slip coefficients of the yarn from the roller and along the surface of the coil 5. Based on the constructive and kinematic nature of the approximate assembly winding machine, we can assume that $\nu_1, \varepsilon_1, H, \ell$ are stationary quantities.

In this case, the tensile strength of the yarn is determined by the following equations:

$$P_0(t) = A_1[\varepsilon_{\min} + \Delta\varepsilon\Phi^2(t)] \tag{9}$$

$$P(t) = P_0(t) - \frac{1}{2}T \cdot \omega_e^2 x^2 \tag{10}$$

We can also ignore the second term in the second equation because no balloon is formed in the motion of the thread in the OA section:

$$P(t) = P_0(t) = A_1[\varepsilon_{\min} + \Delta\varepsilon\phi^2(t)] \tag{11}$$

Using this expression, it is possible to calculate the tensile force acting on the yarn in the section from the tensioning device to the surface of the winding drum during the winding of the paired yarn of the assembly winding machine to the cylindrical coil (Korabayev et al., 2018; Ahmadjanovich et al., 2020; Turdialiyevich & Khabibulla, 2020; Tozhimirzaev et al., 2020). Considering that it would be effective to compare the theoretical calculations performed using the obtained model with the results of experimental studies, the tensile strength was calculated for cotton yarn of linear density T_{yarn} = 25 tex. For T_{yarn} = 25 tex yarn (Fig. 1), we examine in the obtained models the change in tension or tensile force generated in the yarn moving in the section OA at *t*-time. Assuming that the diameter of the cylindrical coil is $d_б = 10см = 0,1м$, and its rotational speed is $\omega_б = 847\dfrac{rpm}{\min} = 14,12\dfrac{1}{c}$, we find:

$$V_1 = V_w = \omega_б \cdot r_б = 14,12 \cdot 0,05\frac{\text{м}}{\text{с}} = 0,706\frac{\text{м}}{\text{с}} \tag{12}$$

$$\nu_1 = \eta_1 \cdot V_{\text{out}}$$

$$\nu = \eta_2 V_{ўр}\sqrt{1+tg^2\alpha_б} = \eta_2 \cdot V_1 \cdot \sqrt{1+tg^2\alpha_б} \tag{13}$$

$$\frac{\nu}{\nu_1} = \frac{\eta_2 V_1\sqrt{1+tg^2\alpha_б}}{\eta_1 \cdot V_{out}} = \frac{\eta_2}{\eta_1}\frac{V_1}{V_{out}} \cdot \sqrt{1+tg^2\alpha_б} = \frac{\eta_2}{\eta_1}K_V\sqrt{1+tg^2\alpha_б} \tag{14}$$

Here, $K_V = \frac{V_1}{V_{out}} = 0{,}982$; $\eta_1 = 0{,}995$; $\eta_2 = 0{,}962$;

From equation (15), $\frac{\nu}{\nu_1} = 1{,}01$.

We perform the calculations in two variants, namely for single and paired yarns.
1- variant. We perform the calculation for a single thread.

$H = 45\text{мм} = 4{,}5\text{см} = 0{,}045\text{м}$; $\ell_1 = 230\text{мм} = 23\text{см} = 0{,}23\text{м}$;

$\alpha_б = 16^0 30^1$; T_{yarn}=25 tex; $E = 9.1 \cdot 10^8 \frac{H}{M^2}$;

$A_1 = 15{,}2H$; $P_4 = 0{,}266H$;

Relative elongation; $\varepsilon_1 = \frac{P_4}{A_1} = 0{,}0175$; $\beta^2 = 0{,}5\left(\frac{H}{\ell_1}\right)^2 = 0{,}02$; $\eta_1 = 0{,}995$; $\eta_2 = 0{,}962$;

2-variant. Let the added yarns acting on the section OA. For paired yarn: T_{yarn}= 25 tex.

In this case: $\varepsilon_1 = \frac{P_4}{2_{A1}} = 0{,}0087$.

Using Expression (4), graphs of the tensile strength of the yarn, the relative deformations over time, and the direction of the spool axis are obtained in MAPLE-17 and are shown in Figures 2-4.

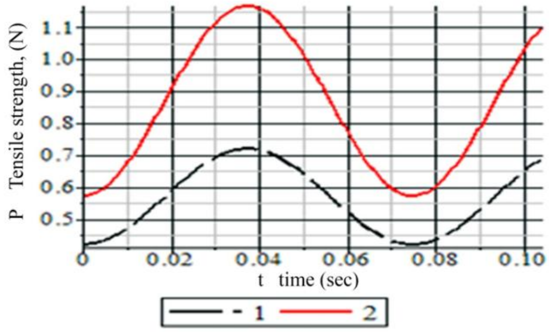

Figure 2. The change in longitudinal tensile force acting on the yarn over time
1- for a single yarn; 2- for a paired yarn

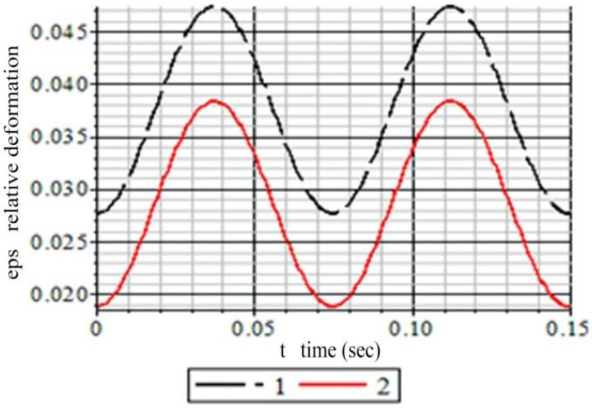

Figure 3. The law of change of longitudinal relative deformation formed in a yarn over time
1- for a single yarn 2-For a paired yarn

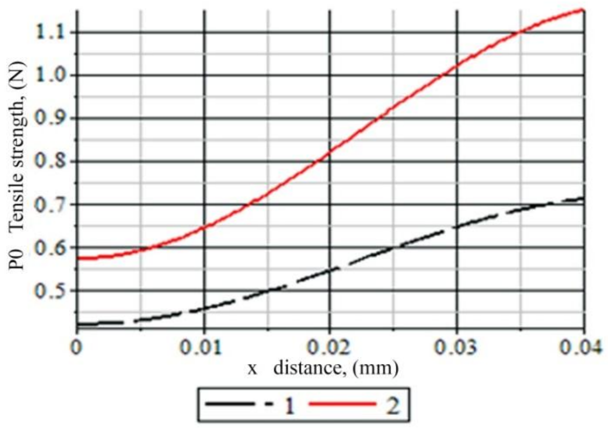

Figure 4. The change in the longitudinal tensile force generated in the cross-section of the yarn along the axis of the coil
1-for a single yarn 2- For a paired yarn

From the graphs in Figures 3 and 4 above, it can be seen that the tensile strength and relative longitudinal deformations of the yarns change according to the laws of harmonic motion during the winding of the yarns into a cylindrical coil. If the process is not subject to any unintended external influences, the parameters analyzed above, which determine the stability of the assembly winding process, will be available according to the law of this change. As a result of the calculation using the obtained mathematical model, along the length of the winding axis, the time is taken to form the windings once was equal to $t_* = 0{,}08$ seconds. During this time, the maximum and minimum values of the tensile strength of the yarn were found to be equal: $P_{\max} = 0{,}07196cH$ for a single yarn at t = 0.037 s and $P_{\min} = 0{,}04207cH$ at t = 0.0 s, respectively. For machine-paired yarns, it was found that $P_{\max} = 0{,}11654cH$ at t = 0.037 s and $P_{\min} = 0{,}05726cH$ at t = 0.0 s. Given the minimum and maximum values of individual and added yarns, it will be possible to select the optimal values of the main technological or design parameters that affect the tension. The importance of their mechanical properties in the formation of quality indicators of twisted yarns is very high. Given this situation, the laws of change in longitudinal relative deformation over time in the winding stage in single and paired yarns have been studied.

The connection diagrams set using the generated models are shown in Figure 3 for single and paired yarns. It can be seen that the maximum and minimum longitudinal relative deformations that occur during the process in the yarn are $\varepsilon_{\max} = 0{,}047$ at t = 0.037 s and $\varepsilon_{\min} = 0{,}0276$ at t = 0.0 s for a single yarn. This relative longitudinal deformation was found to be $\varepsilon_{\max} = 0{,}0383$ at t = 0.037 s and $\varepsilon_{\min} = 0{,}0188$ t = 0.0 s for paired yarns. Figure 4 above shows the laws of variation of the longitudinal tensile force generated in the cross-section of single and paired yarns along the axis of the winding (Miller & Chinzei, 2002; Nuriel et al., 2005). The graph analysis shows that the value of tension and relative deformation during the movement of the binder along the surface of the coil varies according to the harmonic law. If the tension and deformation at the maximum amplitude of the binder reach the maximum value, the bending angle $\alpha_б$ is minimized, and as the binder approaches the center, their quantity decreases according to the above-mentioned regularity.

3 Conclusion

a) Using the obtained mathematical models, it is possible to select the appropriate design values, technological parameters, and kinematic parameters of the working bodies of the equipment, taking into account the value of the yarn tension in the interval $P_{\min} \le P_{opt} \le P_{\max}$.

b) In the area from the pulling to the tensioning device, it was found that the tension of individual yarns and their dispersion is sufficiently small and the required level of strength reserve between the average value of tension and yarn toughness.
c) It has been proved that by optimizing the tension and relative deformation of paired yarns, it is possible to increase the density of the cylindrical winding and the operating efficiency of the equipment.
d) As a result of the theoretical study of the laws of variation of tension in the winding zone of the added yarns, it was found that the difference between their strength is sufficient, that is, the probability of breaking of yarns in this zone is very low.
e) Based on the theoretical research, the change in tension and relative deformation values of yarns along the width of the winding was studied, and the laws of variation of the longitudinal tensile force generated in the cross-section of single and paired yarns along the axis of winding were given. The analysis shows that the value of tension and relative deformation during the movement of the binder along the surface of the coil varies according to the harmonic law.

Conflict of interest statement

The authors declared that they have no competing interests.

Statement of authorship

The authors have a responsibility for the conception and design of the study. The authors have approved the final article.

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