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The Law of Motion in Determining the Tension of the Cocoon Thread

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Annotation: It is studied process removing threads from a cocoon surface at unwinding and influencing factors on change of speed of unwinding. Also it is studied dynamics and laws raw silk winding on a reel, it is presented change of depth of immersing, an immersing corner, and factor of resistance from cocoon radius. The equation and calculations on cocoon movement on the viscous liquid environment are resulted theoretical. Constant factors, and, b and c are presented at various values of factor of viscosity n. From the analysis of tabular data follows, that with parametre growth n the attenuation factor a grows, other parameters b and c at first with growth n at first quickly grow and further vary slightly.

Keywords: cocoon, liquid medium, cocoon thread, immersion, unwinding, rotation.

Introduction. Raw silk, silk threads as well as silk fabrics, knitwear, women's clothing and accessories such as shawls, scarves and other raw silk items are considered the most popular goods on the world market. Foreign countries such as China, India, Brazil, Japan and South Korea have made significant progress in the field of silk production and processing, and pay special attention to improving technologies that improve the efficiency of silk unwinding and raw silk production, as well as ensure the competitiveness of products. At the same time, the lack of varieties of sewing threads, the use of threads with a different fibrous composition in the manufacture of clothes from natural silk, leads to such negative problems during operation, namely in the washing-drying process, as the reduction of seams. Therefore, the improvement of technology and methods for the production of silk threads, the creation of new assortments of them is one of the urgent problems today.

The law of motion of a cocoon, the method of hydrodynamics is studied, and the motion of a cocoon with variable mass in the form of a ball immersed in an aqueous medium is considered. The graphs of the dependence of the displacement of the center of the cocoon (ball) on times for two values of the coefficient of stiffness of the thread $k0$ (N/m) and the time of completion of the cycle t (sec) are presented. The theoretical equation and calculations for the location of the ball in the aquatic environment are presented. The paper studies the effect of thread breakage during cocoon unwinding on the quality of raw silk [1].

There is information on the state of development of the silk industry in Uzbekistan, the tasks set and the work being done. This article describes the causes of defects in the production of high-quality raw silk, the effect of defects in the cocoon shell and methods for their elimination. The effect of the quality of raw silk on the formation of defects in raw silk in silkworm breeding has been studied. the effect of the correct execution of agrotechnical rules on the amount of defective cocoons and the relationship of shell damage during loading were studied. The origin of defects in the process of reeling and methods of their elimination are given. The effect of defective cocoons on the quality of raw silk has been given a practical justification. The results of the experiments are presented in pictures and tables [2].

The article examines the influence of climatic conditions on the technological characteristics of local and Chinese silkworm hybrids (Chofuun Bayye) grown in spring, summer and autumn in the Surkhandarya region. Scientific research was carried out to improve the technological properties of the re-grown cocoon shell and the quality of raw silk, as well as to develop a primary processing technology. The lack of industrial methods of growing cocoons has led to a decrease in attention to the care of mulberry leaves, the nutritional properties of mulberry

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leaves change during the summer, where it is studied to what extent climatic conditions during feeding affect the yield of raw silk [3].

This study reported that this model of rope did not lead to some differentiation or improvement in results compared to other approaches, but that it differed from other approaches in that it reflected an important and useful methodology for visualizing complex systems based on statistical averaging (balancing) methods. [4, 5].

In the present work, the classification of sewing assortments is based on the following characteristics: the purpose of the yarn, raw material composition, method of finishing, as well as structural parameters such as the number of joints, twist direction, linear density (thickness) and others [6, 7].

One of the main factors in improving the socio-economic situation in the country is to improve the technology of preparation of raw materials, increase the efficiency of processing and establish production in a system of interconnected industries to quality finished products [8, 9].

Research results and their analysis: The process of winding silk thread on a reel is accompanied by a continuous change in the radius of the reel, caused by an increase in the layer of the wound product. At the same time, the winding dynamics is also affected by the mechanism of unwinding (removal) from the surface of the cocoon of the thread, which leads to a change in the tension of the thread between the points of winding on the reel and the thread coming off the surface of the cocoon [10-16].

Let us study the process of winding an elastic thread on a reel unwinding from the surface of a cocoon immersed in a viscous medium and performing a two-dimensional motion in it (Fig. 1). The elasticity of the thread is taken into account through the stiffness coefficient k. Let the thread be wound on the drum according to the law $x = x_0(t)$ and relies $x_0(0) = 0$ $\dot{x}_0(0) = v_0$ (v_0 - the initial linear speed of the reel). As a result of the deformation of the thread between points *A* and *B* of the thread, an elastic force arises $F_y = k[x(t) - x_0(t)]$, где $BB_0 = x(t)$ moving vanishing point *B*.

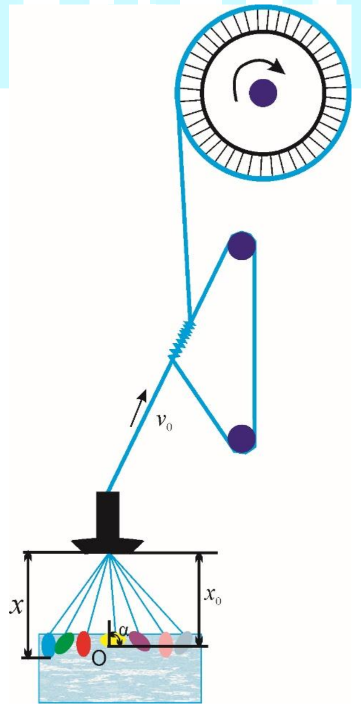

Fig.1. Scheme of cocoon movement in a resisting medium

The cocoon is taken as a cylindrical body (coil) with an axis perpendicular to the drawing plane of length *L*. Let us consider the case of unwinding (removing) the thread from the surface of the cocoon, which occurs without friction, and we assume that the thread layer is unwound along the entire length of the cylinder and does not affect the movement of the cocoon, i.e. at the vanishing point, no force arises that prevents the process of removing the thread from the surface of the cocoon [17-20].

Under these assumptions, point *B* is the point of the instantaneous center of rotation of the cylinder.

If denoted by α the angle between the horizontal and the direction, B_0M, then the absolute speed of a surface point is determined by the formula:

$$v = 2\dot{z}(t)\cos\alpha \qquad (1)$$

Until the start of winding, we assume that the cocoon immersed in a liquid medium is in static equilibrium. In this case, the initial immersion depth h_0 is determined from the condition of equality of the weight of the cocoon and the lifting force, which gives.

$$m_c g = \rho_l g R_c^2 L(\alpha_0 - \sin\alpha_0)/2 \qquad (2)$$

where m_c - mass of cocoon, ρ_l – liquid density, R_c - radius of the cylinder (cocoon). Equation (2) can be written with respect to the cocoon immersion depth, if we take into account the dependence

$$\alpha_0 = \alpha(h_0) = 2\arcsin\frac{\sqrt{2h_0R_c - h_0^2}}{R_c} \qquad (3)$$

Table 1 shows the values of h_0 and α for various cocoon radii R_c. It is assumed in the calculations, $m_c = 1\,g.$, ρ_l = 1000 kg/m^3, L =0,03m.

Table 1. Variation in dive depth, dive angle, and drag coefficient from cocoon radius

$R_c\,(m)$	0,005	0,01	0,015	0,02	0,025	0,03
$h_0(m)$	0,0044	0,00325	0,0023	0,0025	0,0023	0,0022
$\alpha_0(angle)$	166	95,3	71,2	58,3	50,1	44,2

From the analysis of the tabular data it follows that with an increase in the radius of the cocoon (with its constant length *L*), the depth of its immersion in the liquid medium first rapidly decreases and then $R_c \geq 0{,}015$ remains practically constant at.

With a known immersion depth (or immersion angle α), one can find the viscous resistance force acting on the wetted part of the cocoon surface with a linear dependence of this force on the speed of the cocoon using the integral ($\mu_0 = \mu / R_c$, μ coefficient of dynamic viscosity of the liquid).

$$F_c = L\mu_0 \int_0^l v\,dl \qquad (3)$$

Considering dependency $l = R_c\alpha(h)$ (α - in radians) and using formula (1), we find

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$$F_c = 2\dot{z}(t)R_c L\mu_0 \int_{\beta_1}^{\beta_2} \cos\alpha d\alpha = 2\dot{z}(t)\mu_0 L R_c (\sin\beta_2 - \sin\beta_1)$$

where the integration limits β_1 and β_2 depend on the angle α and, according to Fig. 2, are determined by the formulas

$$\beta_1 = (\pi - \alpha)/4, \ \beta_2 = (\pi + \alpha)/4$$

Supplying values β_1 and β_2 in formula (3), we obtain

$$F_c = 2\dot{z}(t)\mu L\sqrt{1-\cos(\alpha/2)} = 2\dot{z}(t)\mu L\sqrt{\frac{h}{R_c}}$$

Now let us compose the equation of motion of the cocoon in the presence of elastic forces of the thread and viscous resistance. The kinetic energy of the cocoon in the process of unwinding is written as [11]:

$$T = \frac{m}{2}\left[\dot{z}^2 + \frac{1}{2}(\dot{z} - \dot{x})^2\right] \qquad (4)$$

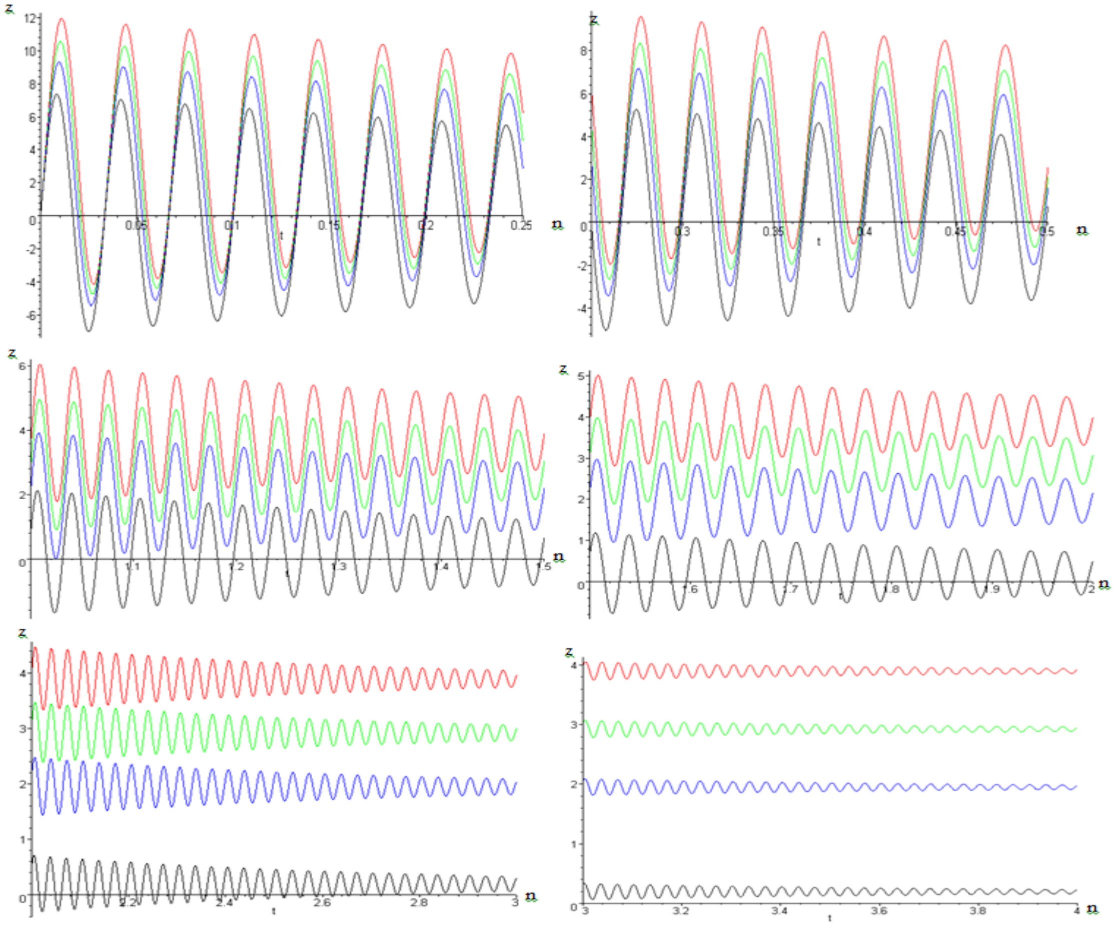

Fig.2. Oscillations of the center of gravity and tension of the cocoon thread depending on the viscosity of the liquid and the mass of the cocoon

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Taking the displacements z and x as generalized coordinates, we compose the Lagrange-II equation of the second kind:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{z}}\right)-\frac{\partial T}{\partial z}=Q_z$$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{x}}\right)-\frac{\partial T}{\partial x}=Q_x \qquad (5)$$

where Q_z and Q_x - are the components of the generalized force, which have the form

$$Q_z=m_c g-\rho_l g R_c^2 L(\alpha-\sin\alpha)/2-C_0(h)\dot{z}\,,\ Q_x=k(x_0-x)\,, \qquad (6)$$

where

$$\alpha=\alpha(h)=2\arcsin\frac{\sqrt{2hR_c-h^2}}{R_c}\,,\ C_0(h)=2\mu L\sqrt{\frac{h}{R_c}}$$

At an arbitrary point in time, the immersion depth is expressed in terms of a variable using $z=z(t)$ the formula $h=h_0-(z_0-z)$. Introducing a new function $\xi(t)$ according to the formula $z=\xi+z_0$ ($\xi=h-h_0$), we reduce system (5) to the form

$$3\cdot m\cdot\ddot{\xi}-m\cdot\ddot{x}=-2C_0(\xi+h_0)\cdot\dot{\xi}+2m_c g-2\rho_l g R_c^2 L[\alpha(\xi+h_0)-\sin\alpha(\xi+h_0)]/2 \qquad (7)$$

$$m\cdot\ddot{x}-m\ddot{\xi}\cdot=2k\cdot(x_0-x) \qquad (8)$$

The system of equations (7) and (8) is integrated under the initial conditions:

$z=z_0,\ \dot{z}=0,\ x=0,\ \dot{x}=0$ at t=0.

For values $\xi<<h_0$ believe $C_0\approx C_0(h_0)$ $\alpha(\xi+h_0)=\alpha(h_0)=\alpha_0$ and according to (2) we have $m_c g=\rho_l g R_c^2 L(\alpha_0-\sin\alpha_0)/2$. Then the system (7) and (8) becomes linear and its solution can be obtained in a closed form.

Introducing a new variable $\tau=\omega\cdot t$ and functions $\bar{z}=\frac{z}{z_0}+1$, $\bar{x}=\frac{x}{z_0}$, $\bar{x}_0=\frac{x_0}{z_0}$ (where $\omega=\sqrt{\frac{2k}{m}}$, R_r - reel radius) equations (7) and (8) are reduced to the form ($\bar{z}'=\frac{d\bar{z}}{a\tau}$, $\bar{z}''=\frac{d^2\bar{z}}{a\tau^2}$, $\bar{x}''=\frac{d^2\bar{x}}{a\tau^2}$):

$$3\bar{z}''-\bar{x}''=-2n\bar{z}' \qquad (9)$$

$$\bar{x}''-\bar{z}''=\bar{x}_0-\bar{x} \qquad (10)$$

Where $n=\frac{\mu L}{m\omega}\sqrt{\frac{h_0}{R_c}}$, The initial conditions for system (9)-(10) will be zero.

The solution of the system of equations (9)-10) will be obtained by the method of operational calculus. Applying the one-sided Laplace transform with respect to the variable τ, we obtain

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$$\hat{z} = \frac{\hat{x}_0(p)}{2} \frac{p}{p^3 + np^2 + 1.5p + n}, \quad \hat{x} = \hat{x}_0(p) \frac{1.5p + n}{p^3 + np^2 + 1.5p + n}$$

$$2\overline{x}''' + n\overline{x}'' + 3\overline{x}' + n\overline{x} = 3\overline{x}_0' + n\overline{x}_0 \tag{11}$$

After determining the function *x(t)* from equation (9), we find the variable coordinate of the center of the cocoon $\overline{z}(\tau)$

$$\overline{z}(\tau) = \overline{z}_0 + \frac{1}{3}\left[\overline{x}(\tau) - \frac{n}{3}\int_0^{\tau} \overline{x}(\xi) e^{-\frac{n}{3}(\tau - \xi)} d\xi\right]$$

The solution of equation (11) is found by the method of operational calculus. Applying the one-sided Laplace transform [11], we obtain:

$$\hat{x} = \hat{x}_0(p)\left[1 - \frac{p^3 + \frac{n}{2}p^2}{p^3 + \frac{n}{2}p^2 + \frac{3}{2}p + \frac{n}{2}}\right] \tag{14}$$

where $\hat{x} = \int\limits_0^{\infty} x(\tau) e^{-p\tau} d\tau, \quad \hat{x}_0 = \int\limits_0^{\infty} x_0(\tau) e^{-p\tau} d\tau,$

Next, we set

$$p^3 + \frac{n}{2}p^2 + \frac{3}{2}p + \frac{n}{2} = (p + a)\left[(p + b)^2 + c^2\right]$$

where the constants a, b, c are expressed in terms of the roots of the equation

$$p^3 + \frac{n}{2}p^2 + \frac{3}{2}p + \frac{n}{2} = 0$$

$$p_1 = -a; \quad p_2 = -b + ic, \quad p_3 = -b - ic.$$

Table 2 shows the constants a, b and c on for various values of the viscosity coefficient n.

***Table 2.* Data for constants *a, b* and *c* for various parameter values n.**

N	0,05	0,1	0,5	1	1,4	1,8	2,2	2,6	3,0	3,4
a	0,016	0,033	0,168	0,343	0,500	0,669	0,852	1,051	1,251	1,473
b	0,004	0,008	0,041	0,077	0,114	0,115	0,123	0,125	0,122	0,116
c	1,225	1,225	1,220	1,200	1,176	1,154	0,132	1,110	1,082	1,071

From the analysis of the tabular data, it follows that with an increase in the parameter *n* (with an increase in viscosity or a decrease in the stiffness coefficient of the thread, or a decrease in the mass of the cocoon), the attenuation coefficient increases a, the remaining parameters *b* and *c* first increase rapidly with an increase in *n* and then change insignificantly.

n formula (14), we introduce instead $\hat{x}_0(p)$ of the image of the dimensionless linear speed of the reel

$$v_0(p)=\int_0^{\infty}\dot{x}_0(\tau)e^{-p\tau}a\tau .$$

Then, taking into account $\hat{x}_0(p)=\dfrac{v_0(p)}{p}$ formula (14), we represent it as:

$$\hat{x}=\hat{v}_0(p)\left\{\frac{1}{p}-\frac{p^2+\frac{n}{2}p}{(p+a)\left[(p+b)^2+c^2\right]}\right\} \tag{15}$$

With a known function $v_0(\tau)$ from (15) we find the displacement $x(\tau)$ [11]

$$x(\tau)=x_0(\tau)-\int_0^{\tau}v_0(\tau-\xi)F_1(\xi)d\xi-\frac{n}{2}\int_0^{\tau}v_0(\tau-\xi)F_2(\xi)d\xi$$

$$F_1=\frac{1}{(b-a)^2+c^2}\left\{a^2e^{-a\tau}+\left[(a-b)+c^2-a\right]e^{-b\tau}\cos c\tau-\left[ac+bc-\frac{(a-b)b^2}{c}-\right]e^{-b\tau}\sin c\tau\right\}$$

$$F_2=\frac{1}{(b-a)^2+c^2}\left[-ae^{-a}+ae^{-b\tau}\cos c\tau-\frac{ab-b^2-c^2}{c}e^{-b\tau}\sin c\tau\right].$$

The thread tension is determined by the formula:

$$N=Rk\left[(x_0(\tau)-x(\tau)\right]=Rk\int_0^{\tau}v_0(\tau-\xi)\left[F_1(\xi)+\frac{n}{2}F_2(\xi)\right]d\xi$$

The Laplace image of the displacement of the center of the cocoon according to (7) is expressed by the formula.

$$\hat{z}=\frac{z_0}{p}+\frac{p\hat{x}(p)}{3p+n}$$

Substituting the expression $\hat{x}(p)$ from (14), we obtain

$$\hat{z}=\frac{z_0}{p}+\frac{\hat{v}_0(p)}{2(p+a)[(p+b)^2+b^2]}$$

Using the inversion theorem [2], we have

$$z=z_0+\int_0^{\tau}v_0(\tau-\xi)\frac{e^{-a\xi}-e^{-b\xi}\cos c\xi+\frac{a-b}{c}e^{-b\xi}\sin c\xi}{(b-a)^2+c^2}d\xi .$$

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Conclusion. From the analysis of tabular data and figures, it follows that with an increase in the parameter n (with an increase in viscosity or a decrease in the stiffness coefficient of the thread, or a decrease in the mass of the cocoon), the attenuation a coefficient increases, the remaining parameters b and c first increase rapidly with an increase in n and then change insignificantly.

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