Investigation of the process of removing the thread from the surface of the cocoon in an aquatic environment

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Abstract. The law of motion of a cocoon, the method of hydrodynamics are 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 $k_0 \ (N/m)$ 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. Introduction
One of the main tasks set by the President of the Republic of Uzbekistan is the development of the textile industry in Uzbekistan, an increase in the volume of finished products that meet the requirements of the modern and world markets. Realizing these tasks, the Government of the Republic of Uzbekistan creates a number of solutions, measures and opportunities. In particular, the Decree of the President of the Republic of Uzbekistan DP-5989 of May 5, 2020 “On urgent measures to support the textile and garment and knitwear industry” [1]. When solving the set tasks, special attention should be paid to the quality of the cocoon, the method of primary processing, the development of new technologies in the silk industry and other factors.

According to its strength, hygienic characteristics, natural silk has the highest rates among natural fibers, therefore, products made from it are in great demand in the international market, but its share in the balance of textile raw materials does not exceed 0.2 percent.

Despite the ongoing large-scale work on the development of the industry, the introduction of modern and innovative technologies, there are still a number of problems that impede the accelerated, deep processing of silkworm cocoons and the production of competitive finished silk products with high added value. In the future, it is necessary to develop new methods and technologies for preparing raw materials and expanding the range of products.

2. Materials and methods
The article studies the process of removing the thread from the surface of the cocoon during unwinding and the factors influencing the change in the unwinding speed. The dynamics and laws of winding raw silk on a reel are also studied, the change in the depth of immersion, the angle of immersion, and the coefficient of resistance from the radius of the cocoon are presented. The theoretical equation and calculations for the motion of a cocoon on a viscous liquid medium are presented. Constant coefficients...
a, b and c are presented for different values of the viscosity coefficient n. From the analysis of the tabular data, it follows that with an increase in the parameter n, the damping coefficient a grows, the remaining parameters b and c first grow rapidly with increasing n and then change insignificantly [2,3].

In this study, schemes for determining the temperature in the composition of living cocoons grown in different seasons under the influence of infrared light are presented and analyzed, and the results of practical studies. The results of applied research have shown that the distance between the cocoon and the lamp affects the temperature of the cocoon components. Treatment of cocoons under the influence of infrared light averages the temperature of the pupa in short time. It was found that it can be increased to 790 ° C and that the temperature of the cocoon shell is on average 270 ° C lower than that of the pupa. Due to the fact that the process of anesthesia of cocoons grown in spring can be carried out in a shorter time than in the second season, and they are not exposed to high temperatures, keeping the technological parameters of the shell at a high level. Silk gauze, bandages, napkins [4,5].

In this work, the effect of thread breakage during cocoon unwinding on the quality of raw silk was studied. Theoretical and practical studies have shown that, as a result, the control of linear densities can produce raw silk in accordance with the international standard of the class “3A”. The study of the unwinding speed, thread tension and the forces acting on it during unwinding made it possible to obtain high-quality raw silk. Determined the rational speed of unwinding [6-8].

Scientists from the School of Materials Science and Engineering of Beijing University (China, Beijing) and the Department of Zoology of the University of Oxford (Great Britain, Oxford) [9-11] propose dynamic mechanical thermal analysis or DMTA for assessing the quality of "silk", facilitating the classification of silk cocoons, and quantifying the impact of industrial processing (temperature, humidity and load). Through experimental testing of cocoons and raw silk in three grades, static differences in mechanical properties were revealed. The degree of disordered molecular structure in each silk can be calculated from the tangential (tan) profiles of DMTA loss, and lower grades of silk appear to have a more disordered structure. It has also been found that heat treatment under heat stress can "improve" these poor silk structures and reduce the distinction between poor and quality silk. The researchers conclude that DMTA is a sensitive and very powerful method that can reveal links between growing and production conditions and the final quality and properties of silk.

The production of bulk raw silk is preferable for sari weaving in the Indian context. It was believed that the speed of movement of the cocoons would be increased by the inclusion of a suitable device, so that tangling of the fibers would occur, resulting in a different structure of bulky silk yarn. CSTRI has developed a mechanism for rotating the inner vessel while keeping the outer vessel constant; thus, water will not be spilled during the rotation of the boat during the winding process. To standardize process parameters such as pelvic velocity (vessel rotation), drum rotation speed and the number of cocoons wound to produce bulk raw silk by entangling cocoons using the Box and Behnken experimental design. Studies have shown that the average denier, uniformity in size and deviation in size are significantly dependent at the level of 1% of the above process variables. In addition, it was noted that the speed of the pelvis and the speed of the reel should be in a ratio of 2:1. The speed of the pelvis 150 rpm at a drum speed of 75 rpm and 30 cocoons gave the yarn the necessary bulk and characteristics suitable for the production of bulky silk fabric, which can be used exclusively for final purposes [12].

The silk cocoon is the only raw material for the silk industry. In the cocoon trade, the price of the cocoon is determined by the assumption that it contains silk. A human expert visually inspects the cocoon by its shape, size, color, etc. And feels the strength of the cocoon by pressing on it with his thumbs. This process is subjective and varies from person to person. Invasive methods are used to assess the content of silk in cocoons, but these methods are time consuming, expensive, labor intensive, laboratory-oriented, and difficult to implement on a large scale. Thus, it is important to develop a methodology to assess the content of silk in cocoons in a non-invasive manner. This article proposes a non-destructive X-ray imaging method for assessing the content of silk in a cocoon. This technology applies advanced image processing with appropriate data analysis techniques. First, various important features were extracted from the X-ray image. The aim of the project was to develop a suitable mathematical model for evaluating the silk content of the cocoon. As part of this study, three neural
network models were examined, namely General Regression Neural Network (GRNN), Radial Basis Function Neural Network (RBFNN) and Forward Back Propagation Neural Network (FFBPNN). A comparative study shows that a general regression neural network (GRNN) provides the best performance with a reasonable accuracy of 85% [13].

As you know, the process of removing the filament from the surface of the cocoon is often implemented in an aquatic environment, where the cocoon is immersed in it at a certain depth. The nature and quality of removal is influenced, in addition to the force of adhesion of the thread in the surface of the cocoon, also by the law of motion of the center of motion of the cocoon in the aquatic environment. In this case, the law of motion of the cocoon in it is determined by hydrodynamic methods, which is established for the simplest bodies of revolution. Consider the motion of a cocoon with variable mass in the form of a ball immersed in an aqueous medium (figure 1).

![Figure 1. The layout of the ball in the aquatic environment.](image)

The medium is taken as an ideal incompressible fluid, which occupies the lower half-space \( z \geq 0 \), and a ball of radius \( R \) moves in it according to the law \( h = h(t) \). Set the origin at the exit point \( O \) and direct the axis \( OZ \) in the direction of the ball's motion, axes \( Oy \) and \( Ox \) perpendicular to it. We introduce the velocity potential \( \phi(x, y, z) \), which satisfies the Laplace equation.

\[
\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2} = 0
\]

In this case, the boundary conditions \( \phi = 0 \) at \( z = 0 \).

\[-\infty < x < \infty, \quad -\infty < y < \infty \]  \hspace{1cm} (2)

\[
\frac{\partial \phi}{\partial r} = \dot{h}(t) \cos \theta \quad \frac{1}{r} \frac{\partial \phi}{\partial \theta} = \dot{h} \sin \theta \quad \frac{\partial \phi}{\partial \epsilon} = 0 \quad \text{on the surface of the ball} \]  \hspace{1cm} (3)
Where \((r,\theta,\varepsilon)\) are spherical coordinates, with the help of which the Cartesian formulas are expressed \(x = r \cos \varepsilon \sin \theta, y = r \sin \varepsilon \sin \theta, z = h(t) + r \cos \theta, r = \sqrt{(z-h)^2 + x^2 + y^2}\).

An approximate solution of the equation for large values of the ratio \(u/R\) or (small ratios \(R/h\)) is presented in [14].

\[
\varphi = g_R^2 \hat{h} \frac{\partial}{\partial z} \left( \frac{1}{r_1} - \frac{1}{r_2} \right)
\]

Where \(r_1 = \sqrt{(z-h)^2 + x^2 + y^2}, r_2 = \sqrt{(z+h)^2 + x^2 + y^2}\).

The equation of motion of the ball is obtained in the form:

\[
\frac{d}{dt} \left[ m + \frac{2\pi R^3}{3} \rho \left( 1 + \frac{3 R^3}{8 u^3} \right) \right] + \frac{3\pi \rho R^6}{8h^4} \hat{h}^2 = P
\]

(4)

Where \(m\) is the mass of the cocoon, \(\rho\) is the density of the aqueous medium, \(P\) is the external force acting on the cocoon, which is determined by the formula:

\[
P = k_1 \frac{k_0}{k_0 + k_1} [x_0(t) - h]
\]

(5)

Where \(k_1 = k_1(t) = (k_{max} - k_{min})(1 + \cos \pi t/t_{op})/2 + k_{min}, k_0, k_{min}, k_{max}\) the stiffness coefficients characterizing the elastic properties of the formed thread and the resistance forces when removing the thread from the surface of the cocoon, \(t\) the time of completion of the removal of the thread in one cycle, determined experimentally, \(x_0(t)\) the law of the reel movement.

We assume that the point of removal along the circle \(r = R\) on the surface of the cocoon moves according to the law \(s = s_0(t)\). In this case, the cocoon in the process of lifting makes a rotational movement around the axis \(Ox\), the equation of which is written in the form:

\[
\frac{4m}{5} R^2 \ddot{\varphi} = R_1 \cos(s) \frac{k_1 k_0}{k_0 + k_1} [x_0(t) - h]
\]

(6)

For the initial stage of the cocoon movement, we assume \(m = m_0 = const\) equation (4) taking into account (5) we reduce to the form:

\[
\left[ m_0 + \frac{2\pi R^3}{3} \rho \left( 1 + \frac{3 R^3}{8 u^3} \right) \right] \ddot{h} - \frac{3\pi \rho R^6}{8h^4} \dot{h}^2 = \frac{k_1 k_0}{k_0 + k_1} [x_0(t) - h]
\]

(7)

Equalities (6) and (7) form a system for determining the displacement of the center of the cocoon \(h\) and the angle of rotation \(\varphi\) about its axis \(Ox\).

If we do not take into account the influence of the free boundary of the aqueous medium, then equation (7) is written in the form:

\[
\left[ m_0 + \frac{2\pi R^3}{3} \rho \right] \ddot{h} = \frac{k_1 k_0}{k_0 + k_1} [x_0(t) - h]
\]

(8)
Here the value $2\pi\rho R^3/3$ defines the added mass of the liquid.

Equation (8) is reduced to the form:

$$\ddot{h} + \frac{\omega^2}{1 + k_i} h = \frac{k_i}{1 + k_i} x_0(t)$$

(9)

Where $\omega = \sqrt{k_0 / M_0}$, $\bar{k}_i = (\bar{k}_{\text{max}} - \bar{k}_{\text{min}})(1 + \cos \pi t / t_{np}) / 2 + \bar{k}_{\text{min}}$, $M_0 = m_0 + 2\pi\rho R^3 / 3$.

At $\bar{k}_{\text{max}} << 1$, we put $\frac{\bar{k}_i}{1 + \bar{k}_i} \approx \bar{k}_i$. Then equation (9) is written as.

$$\ddot{h} + \omega^2((\bar{k}_{\text{max}} - \bar{k}_{\text{min}})(1 + \cos \pi t / t_{np}) + \bar{k}_{\text{min}}) h = \bar{k}_i x_0(t)$$

Putting $2\tau = \pi / t_{np} + \pi$, $a = 4\omega^2 t_{np}^2 \bar{k}_{\text{max}} / \pi^2$, $2\varepsilon = 4\omega^2 t_{np}^2 (\bar{k}_{\text{max}} - \bar{k}_{\text{min}}) / \pi^2$ we bring the last equation to the form:

$$\frac{d^2h}{d\tau^2} + (a - 2\varepsilon \cos 2\tau) h = \frac{4\omega^2 t_{np}^2}{\pi^2} \bar{k}_i x_0\left[\frac{(2\pi - \pi) t_{np}}{\pi}\right]$$

(10)

3. Results and discussion

Equation (10) without the right-hand side is called the Mathieu equation, which describes the process of parametric oscillation [15]. The properties of this equation have been studied in detail, according to which its solutions can be bounded or infinitely increasing. The selection of the areas of parameters $a$ and $\varepsilon$ corresponding to this case leads to the stability diagram, which is given in finished form (the Ainis - Strett diagram) in plane $(a, \varepsilon)$. Periodic movements correspond to the boundaries between the regions of stability and instability.

![Figure 2](image1.png)

**Figure 2.** Dependences of displacement $h$ (m) (a) and speed $v$ (m/s); (b) of the center of mass of the cocoon on time $t$ (sec) at $t_c = 1$ (sec) and $k_0 = 5 \text{ N/m}$. 
Figure 3. Dependences of displacement $h$ (m) (a) and speed $v$ (m/s) (b) of the center of mass of the cocoon on time $t$ (sec) at $t_c = 1$ (sec) and $k_0 = 2 \, N/m$.

Figure 4. Dependences of displacement $h$ (m) (a) and speed $v$ (m/s) (b) of the center of mass of the cocoon on time $t$ (sec) at $t_c = 1$ (sec) and $k_0 = 2 \, N/m$.

Figure 5. Dependences of displacement $h$ (m) (a) and speed $v$ (m/s) (b) of the center of mass of the cocoon on time $t$ (sec) at $t_c = 0.1$ (sec) and $k_0 = 2 \, N/m$. 
Let us consider the case when the filament is removed at a constant speed $v_0$, i.e., we assume $x_0 = v_0 t$. Equation (9) is integrated numerically with zero initial conditions. Figures 2 and 3 show the graphs of the dependence of the displacement of the center of the cocoon (ball) on times $t$ (sec) for two values of the stiffness coefficient of the thread $k_0$ (N/m) and the cycle completion time $t_c$ (sec). In the calculations $k_{max} = 20$ N/m, $k_{min} = 20$ N/m, $R = 0.01$ m, $m_0 = 0.05$ kg, $\rho = 1000$ kg/m$^3$, $v_0 = 0.5$ m/s.

4. Conclusion

From the analysis of the curves shown in figure 2 - 5 it follows that the center of mass of the cocoon moves upward mainly with a positive speed. In this case, for the values of the stiffness coefficient $k_0 = 5$ N/m and the cycle time $t = 1$ sec, the cocoon can move according to a law close to the parametric one, according to which the movement in a short time can increase rapidly. At $t = 0.1$ sec, this pattern disappears. This phenomenon can be seen when observing the process of the cocoon rising from the aquatic environment.

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