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THEORETICAL ANALYSIS OF THE COEFFICIENT OF FRICTION INDUCED BY THE PRESSURE FORCE OF A VERTICAL ROPE ACTING FROM ABOVE AND BELOW

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Abstract: This article presents a theoretical study of the coefficients of friction between a rope and a vertical pole when pressure forces are applied from above and below. To facilitate understanding of the mechanical processes, illustrations are provided. A mathematical relationship is established between the angle of the rope's winding around the pole and the work done by the frictional force. In developing this relationship, a small surface area is selected, and the characteristics of the forces acting on that area are examined. The results obtained are applied to the entire surface. Utilizing the solution of the established equation, a function relating the work of the frictional force to time is formulated, and its graph is presented. The plotted graphs fully represent the processes in practice, thereby confirming the theoretical and mechanical accuracy of the studied object.

Keywords: weaving, fabric, technology, weaving machine, rope, pole, resistance force, winding angle, coefficient of friction, force, elasticity, deformation.

Introduction. Weaving is undoubtedly one of the oldest arts and crafts in the world. Humanity began to utilize its hands as a "natural" tool for labor, seeking ways to facilitate its livelihood and creating various objects. One of the simplest methods of such creativity involved intertwining strips of animal hides, grasses, reeds, reeds, and branches of bushes and trees. Ancient people placed these materials side by side and intertwined them, resulting in the creation of specific objects. Thus, the simplest form of weaving emerged through this process. The earliest clothing, footwear, blankets, baskets, and nets were the first weaving artifacts. Historically, it is known that weaving preceded spinning. Weavers had knowledge of weaving before they learned to spin yarn.

Artifacts of weaving have been discovered as a result of extensive archaeological excavations in regions between the Nile, India, China, the Amu Darya, and the Syr Darya, as well as in Peru and Mexico. These artifacts confirm that weaving emerged due to humanity's natural inclination to create, and at the same time, it developed independently in various parts of the world. In the earliest weaving looms, the pole was placed upright and tied to horizontal branches made of wood. This arrangement of the pole was convenient for the weaver, as weights hung from the base kept it taut. With the development of weaving, weaving looms were improved. The advancement of these looms led to the invention of devices for holding the pole and collecting raw materials.

After gaining independence, Uzbekistan witnessed significant changes in all sectors of production, including the textile industry. In 1993-1994, advanced foreign textile technology was among the first to be introduced to the Bukhara Textile Manufacturing Association (currently

Buhoroteks JSC). State-of-the-art equipment such as the automatic spinning system from Switzerland's "Reiter," the combing machine from "Beninger," the sizing machine from Germany's "Zukker Muller," and high-performance weaving looms for towel fabric production from Switzerland's "Sulzer Ryuti" were installed. These technologies not only increased production efficiency but also raised product quality to a level that could compete in global markets.

As is well known, cotton fiber and yarn spun from it hold a leading position among Uzbekistan's export products today. One of the key branches of the textile industry is weaving. The strength of the material depends on the durability and quality of the yarn spun. Special devices are used to test the strength of the yarn. However, these devices cannot fully reveal the physical and mechanical properties of the yarn. Instead, the process is mainly understood through practical experience and experimentation.

Figure 1. Weaving of weft yarn into the warp

Materials and Methods. In the operational mode of weaving machines, the weft yarn is woven into the warp. During the weaving process, the yarn wraps around the upper and lower sections of the warp at a specific angle (**see Figure 1**).

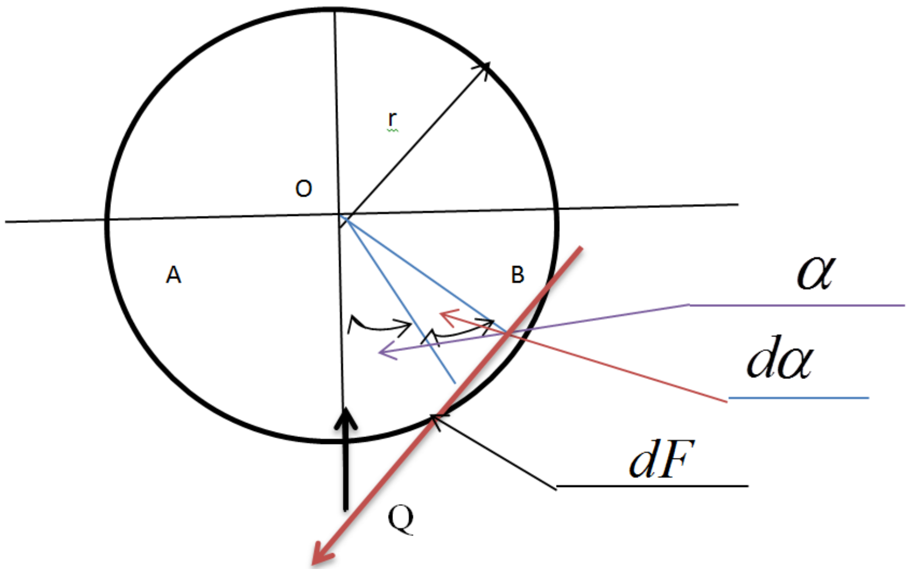


Figure 2. The effect of force Q applied from above on the warp

Let us now examine the parameters that influence the friction in the warp. When a constant force is applied to the weft yarn, pressure forces begin to act on the warp from both above and below. Let's consider how these pressure forces affect the warp from the top and bottom. In studying this process, we must determine the frictional force or the work of the frictional force, as this is a mechanical process. There are two hypotheses for the upper and lower states, and we will explore both of them.

First Hypothesis. In this hypothesis, the weft yarn and the warp are regarded as a kinematic pair in rotation, and the pressure of the yarn on the warp is distributed evenly over the elements of the kinematic pair. In other words, the specific pressure is assumed to be a constant value. Let AB be the elements of the kinematic pair (**see Figure 2**). All the variables mentioned below are presented in **Table 1**. Let's isolate the infinitesimal surface element ds from the warp and yarn elements.

$$ds = lrd\alpha \tag{1}$$

The reaction force corresponding to the infinitesimal surface of the warp is found using formula (2) [4,5].

$$dT = pds \tag{2}$$

By applying formulas (1) and (2), we derive formula (3).

$$dT = prld\alpha \tag{3}$$

Along the y-axis: Since the yarn and the warp are at rest, we can write the equilibrium condition as the following formula (4) [6,7].

$$\sum y = -Q + \int_{-\alpha_0}^{\alpha_0} prl\cos\alpha d\alpha = 0 \tag{4}$$

By integrating formula (4), we derive the following formula (5).

$$Q = 2prl\sin\alpha_0 \tag{5}$$

Using formula (5), we derive formula (6).

$$p = \frac{Q}{2rl\sin\alpha_0} \tag{6}$$

According to Coulomb-Amontons' law, we can express the following equation (7) [8,9].

$$dF = fdT \tag{7}$$

The yarn is moving in the direction opposite to the clockwise rotation in the warp. Using formulas (7) and (3), we write formula (8).

$$dF = fprld\alpha \tag{8}$$

Since the movement occurs along a circular path, the moment of the infinitesimal frictional force is as follows (9) [10,11].

$$dM = rdF \tag{9}$$

By using formulas (6), (8), and (9), we derive formula (10).

$$dM = \frac{fQrd\alpha}{2\sin\alpha_0} \quad (10)$$

By integrating both sides of equation (10), we calculate the value of M (11).

$$M = \frac{fQr\alpha_0}{\sin\alpha_0} \quad (11)$$

Results. We determine the amount of energy required to stretch the yarn over a distance of x_0. This energy equals the work done to overcome the frictional force (or moment) (12).

$$A = \frac{fQx_0\alpha_0}{\sin\alpha_0} \quad (12)$$

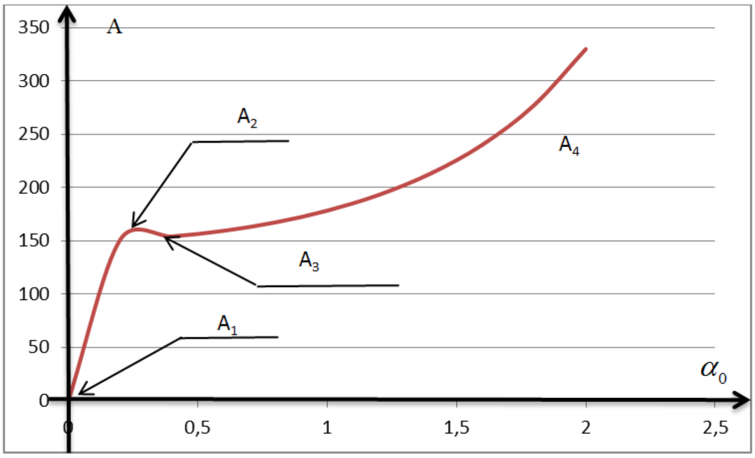
As can be seen from formula (11), the work of the frictional force increases linearly as the distance of the stretch increases. Let's plot the graph showing the relationship between the work of the frictional force and the wrapping angle. All the variables are given in Table 1.

Table 1.

Symbol	Scientific Name	SI Unit
T	Reaction force acting on the yarn	N
P	Pressure acting on the yarn	Pascal
l	Length of the yarn wrapped around the warp	m
S	Cross-sectional area	m^2
R	Radius of the warp	M
α_0	Wrapping angle of the yarn around the warp	rad
v	Velocity of the yarn	m/s
f	Coefficient of friction between the yarn and the warp	-
M	Moment exerted by the yarn on the warp	N*m

We consider $A(\alpha_0)$ in formula (12) as a function of α_0 and plot the graph of their relationship.

Figure 1



IV. **Discussion of Results**

Let's analyze Figure 1 from a mechanical perspective:

A_1A_2: In this interval, we observe a sharp increase in the work done by the frictional force. The primary reason for this process is that the coefficient of static friction is higher than the coefficient of kinetic friction, and the area of force application increases progressively.

A_2A_3: In this interval, the rope begins to move. Once the rope starts moving, the work done by the frictional force decreases due to the reduction in the static friction coefficient. Additionally, the tension in the rope reduces the contact surface between the rope and the object.

A_3A_4: In this interval, the work done by the frictional force increases again, as the reaction force becomes proportional to the speed of the rope.

Second Hypothesis

According to this hypothesis, the object is considered absolutely rigid, meaning it neither compresses nor stretches, and the force \(Q \) is applied in the direction of the line of action. The wear of the object along the vertical axis is assumed to remain constant (12). Figure 3

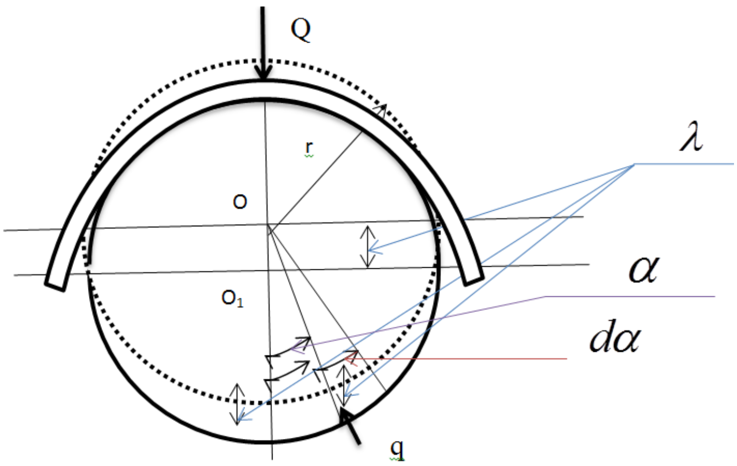


Figure 3. The application of force Q from below on the object

Friction on the object:

$$(\lambda = ac = const) \qquad (13)$$

The radial pressure force acts on the BC section of the object. This force is considered proportional only to the specific pressure when the rope rotates at a constant linear velocity (14).

$$\overline{bc} = qk \qquad (14)$$

Here, k is the proportionality coefficient.

Using **Figure 3**, we derive equation (15).

$$\overline{bc} = \overline{ac}\cos\alpha \qquad (15)$$

By applying formulas (13), (14), and (15), we derive formula (16).

$$q = \frac{\overline{bc}}{k} = \frac{\overline{ac}\cos\alpha}{k} = \frac{\lambda\cos\alpha}{k} \qquad (16)$$

$$p_0 = \frac{\lambda}{k} = const \qquad (17)$$

By using (16) and (17), we will obtain (18)

$$q = p_0 cos\alpha \qquad (18)$$

We find the relationship for p_0. To do this, we project all the forces onto the vertical axis, resulting in the following equation: (19).

$$Q = 2\int_0^{\frac{\pi}{2}} qrl\cos\alpha d\alpha \qquad (19)$$

Using formulas (18) and (19), we obtain equality (20).

$$p_0 = \frac{2Q}{\pi rl} \qquad (20)$$

Using equation (20), we can calculate the specific pressure. (21)

$$q = p_0\cos\alpha = \frac{2Q}{\pi rl}\cos\alpha \qquad (21)$$

We can find the reaction force on the elementary surface by calculating the pressure applied to that surface. (22).

$$dN = qrld\alpha, \ fdN = dF \qquad (22)$$

The work done on the elementary segment when the rope is pulled a distance of x_0 is determined by the following formulas:

$$dA = \frac{x_0 dM\omega}{v} = \frac{x_0 dFr\omega}{v} = \frac{fqlr^2\omega t_0 d\alpha}{v} = fqrlx_0 d\alpha$$

(23)

Using formulas (23) and (21), we write formula (24).

$$dA = \frac{2Qfx_0}{\pi}\cos\alpha d\alpha \qquad (24)$$

By integrating equation (24), we can determine the work done by the frictional force between the ropes over a duration of (x0) seconds, expressed as equation (25).

$$A = \frac{4Qfx_0}{\pi}\sin\alpha \qquad (25)$$

It can be observed from equation (25) that as the angle of winding increases, the work done by the frictional force also increases.

From equations (12) and (25), it is evident that the work done by the frictional force generated by the forces acting on the object from above and below is primarily dependent on the angle of winding and the coefficient of friction.

V. Conclusions

In conclusion, to enhance the strength of the rope in fabrics, it is essential to consider the forces acting on the rope, its deformation, the interaction between loops and cords, the frictional force resulting from their mutual compression, the coefficient of friction between the ropes, and the type of winding.

Analysis of the literature indicates that very few studies have been conducted on the strength of fabrics. Most of the research focuses on factors such as the height and density of looped fibers and the significance of density along the cord during the moisture absorption process in pile fabrics.

In our investigation of the mechanical process, when developing the winding composition of the rope, it is crucial to improve the quality characteristics of the fabric, particularly the hygroscopic and water-repellent properties. This can be achieved by converting the central layers of the fabric structure from a surface layer to a cord layer, thereby reducing surface area and minimizing energy waste, which in turn increases the strength of the rope.

In fabric weaving, the bonding forces of a single loop allow for the determination of the quantitative values of the elastic force of the rope (Young's modulus) during stretching and compression. Ropes made from natural and synthetic fibers must perform under the influence of compressive deformation during technological processes, especially weaving and knitting. It is necessary to determine the viscoelastic properties of materials under compression, for which the Poisson's ratio is recommended.

The theoretical assessment of how the thickness of the rope affects its breaking strength has been established. Based on the analysis of the conducted research, the strength of the single-loop bonding can be conditionally represented as comprising three forces related to the base system of the fabric, and formulas have been proposed for determining each of these forces, along with a formula for calculating their overall value.

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