

Dependence of Torque on Rotational Speed in A Screw Conveyor Transporting Undried Cotton

Marasulov Islombek Ravshanbek o'g'li

Scientific researcher, Senior Lecturer of the Department of "Intelligent Control and Robotics," Andijan state technical institute, Uzbekistan

Received: 10 February 2026; **Accepted:** 08 March 2026; **Published:** 28 March 2026

Abstract: This article presents a theoretical investigation of the dependence of the torque generated during the operation of a screw conveyor transporting undried cotton on the rotational speed. The study is based on mechanical modeling and analytical calculations, taking into account the fibrous structure, high moisture content, and compressibility of undried cotton. A mathematical model describing the nonlinear relationship between torque and rotational speed is proposed. Based on theoretical graphs, the energy load of the screw conveyor is analyzed, and the existence of an optimal operating regime is substantiated. The obtained results can be applied in the design of screw conveyors and in the selection of electric motor power.

Keywords: Screw conveyor, undried cotton, torque, rotational speed, energy consumption, mathematical model, friction force.

Introduction: The rotational speed is the main controllable parameter of the screw conveyor operating process, as it determines the degree of cotton compaction inside the screw, the magnitude of friction forces, and centrifugal forces. Therefore, expressing the torque as a function of rotational speed fully reflects the physical essence of the process of transporting undried cotton. In the cotton cleaning and drying industry, the continuous and reliable operation of technological processes largely depends on the correct selection and efficient performance of conveying mechanisms. In these processes, screw conveyors are widely used to transfer raw cotton from one technological machine to another. In particular, in transport sections located between the separator and the drying drum, screw conveyors provide continuous, relatively compact, and technologically convenient transportation of cotton.

Undried cotton fundamentally differs from many granular or free-flowing materials. It has high moisture content and, due to its fibrous structure, exhibits

interlocking ability, compressibility, and elastic properties. These characteristics complicate the movement of cotton inside the screw conveyor, lead to increased friction forces, material compaction, and, in some cases, clogging. As a result, the torque on the electric motor shaft increases significantly, and the energy efficiency of the conveyor decreases.

Experimental observations show that if the rotational speed of the screw conveyor is chosen incorrectly, two types of negative conditions may occur. In the first case, when the rotational speed is too low, cotton does not move sufficiently inside the screw, becomes compacted, and the conveying process becomes unstable. In the second case, excessively high rotational speed intensifies the effect of centrifugal force, causing cotton fibers to be pressed against the inner wall of the conveyor casing, which leads to a sharp increase in friction resistance and energy consumption. Both cases reduce the reliability of the mechanism and negatively affect the efficiency of the technological process.

To date, most scientific studies devoted to the analysis of screw conveyor operation have focused on free-flowing or slightly compressible materials such as grain, sand, and cement. However, for fibrous and moist materials, particularly undried cotton, the dependence of torque on rotational speed, the nonlinear nature of loading, and the patterns of energy consumption variation have not been sufficiently investigated. This has led in practice either to the selection of screw conveyors and electric motors with excessive safety margins or, conversely, to the choice of insufficient motor power. In this regard, determining the dependence of torque on rotational speed in screw conveyors transporting undried cotton, revealing the physical nature of this relationship, and substantiating an optimal operating regime constitute an urgent scientific and practical problem. Solving this problem makes it possible to reduce energy consumption, increase equipment service life, and ensure the stability of technological processes in cotton cleaning and drying enterprises.

The purpose of this study is to theoretically investigate the dependence of torque on rotational speed in a screw conveyor transporting undried cotton based on analytical calculations, to develop a mathematical model, and to determine the most energy-efficient rotational speed.

METHODS

This section provides a detailed description of the object and subject of the study, the main physical and mechanical properties of the conveyed material, the theoretical basis for determining torque, and the methodology of experimental investigations. When selecting the research methods, particular attention was paid to the specific influence of the fibrous structure and moisture content of undried cotton on the operating process of the screw conveyor.

Research object and design features. The research object is a horizontal screw conveyor installed in the technological line of a cotton processing enterprise between the **separator** and the **drying drum**. The conveyor consists of a steel screw with a constant pitch spiral as the main working element, placed inside a cylindrical metal casing. The screw is connected to an electric motor through a gearbox, and its rotational speed is smoothly controlled by means of a frequency

converter.

Although this design ensures continuous transportation of cotton, when handling undried cotton it may lead to uneven material distribution inside the screw, compaction, and, in some cases, local clogging. Therefore, determining the rotational speed of the conveyor and the corresponding torque is of significant importance.

Physical and mechanical properties of undried cotton.

Undried cotton, as the conveyed material, exhibits highly complex mechanical behavior. During the study, the following key properties were taken into account:

- moisture content: 10–14%,
- bulk density: 60–90 kg/m³,
- interlocking and elastic properties of fibers,
- increase in resistance forces during compression.

The presence of moisture increases friction between cotton fibers, restricting the free movement of the material inside the screw. In addition, with an increase in rotational speed, cotton fibers are pressed against the inner wall of the conveyor casing under the action of centrifugal force, which further increases friction forces at the cotton–metal interface. These factors lead to a **nonlinear dependence of torque on rotational speed**.

Main parameters of the screw conveyor. In the theoretical analysis, the screw conveyor is characterized by the following parameters:

- D – outer diameter of the screw, m;
- S – screw pitch, m;
- n – rotational speed, rpm;
- ρ – bulk density of undried cotton, kg/m³;
- φ – filling coefficient.

$$\omega = \frac{2\pi n}{60}$$

Movement of undried cotton inside the screw. During its movement along the screw, undried cotton is subjected to the combined action of gravitational force, internal friction, and friction between cotton and metal surfaces. These resistive forces determine the tangential force required to ensure the displacement of

cotton along the screw.

Mass throughput of the screw conveyor

$$Q = 3600 \cdot \rho \cdot \varphi \cdot \frac{\pi D^2}{4} \cdot S \cdot n$$

Force Required to Move Cotton

Undried cotton inside the screw conveyor is assumed to move as a continuous layer. During the conveying process, the cotton is subjected to the action of the following forces:

1. Gravitational force

$$G = mg$$

2. Friction forces between cotton–screw and cotton–casing

The mass of cotton transported along the screw conveyor per unit time is defined as:

$$m = Q$$

where:

Q – mass throughput of the screw conveyor, kg/s.

The mass of cotton conveyed per unit time is directly proportional to the rotational speed of the screw. Consequently, as the rotational speed increases, the force required to move the cotton also increases.

If the mass throughput Q is given in kg/h, it should be converted to seconds for calculations.

Cotton exerts pressure on the surfaces of the screw and the casing due to its own weight. The average normal force is determined as:

$$N = mg$$

The friction force between the cotton and the screw, as well as between the cotton and the casing, is expressed by:

$$F_{fr} = \mu \cdot N$$

where:

μ – coefficient of friction between cotton and metal.

Substituting the normal force into the friction force expression yields:

$$F_{fr} = \mu \cdot mg$$

This friction force constitutes the main component of resistance that must be overcome by the screw conveyor during the transportation of undried cotton.

Here, the **normal force** is directly related to the **weight of the cotton**.

In the case of **undried cotton**, the following additional factors must be taken into account:

- inter-fiber interlocking;
- compressibility;
- effect of moisture.

These factors increase the effective friction force beyond that predicted by simple Coulomb friction. Therefore, a **correction coefficient** is introduced in experimental practice:

$k > 1$

As a result, taking into account the increased resistance caused by the fibrous structure, compressibility, and moisture of undried cotton, the **effective force required to move the cotton** along the screw conveyor can be written as:

$$F = \mu \cdot m \cdot g \cdot k$$

Expressing the mass in terms of throughput:

$$m = Q$$

As a result, the force resisting the movement of cotton is determined as:

$$F = Q \cdot g \cdot \mu \cdot k$$

where:

μ – coefficient of friction between cotton and metal surfaces (*typically 0.2–0.4*);

k – correction coefficient accounting for moisture content and material compaction (*typically 1.2–1.4*).

Derivation of the Torque Model

A screw conveyor transporting undried cotton consists of the following mechanical elements:

- a rotating screw;
- a mass of cotton moving inside the screw;
- the conveyor casing.

To move the cotton axially along the conveyor, the screw generates a **tangential force**, which in turn produces a **torque** on the screw shaft.

According to the laws of mechanics, the torque acting on a rotating body is defined as:

$$M = F_t \cdot r$$

where:

- F_t – tangential force resisting the movement of cotton, N;
- r – radius of the screw, m.

Therefore, the determination of the **torque** of the screw conveyor is directly dependent on determining the **force required to move the cotton** along the screw.

The force determined in the previous step is:

$$F = Q \cdot g \cdot \mu \cdot k$$

The throughput is directly proportional to the rotational speed:

$$Q = C \cdot n$$

where:

C – proportionality coefficient that combines the geometric parameters of the screw and the physical-mechanical properties of cotton.

$$C = 3600 \cdot \rho \cdot \varphi \cdot \frac{\pi D^2}{4} \cdot S$$

that is:

- ρ – bulk density of cotton;
- φ – filling coefficient;
- D – screw diameter;
- S – screw pitch.

If these parameters remain constant, the proportionality coefficient C also remains constant.

When the screw makes one revolution, it conveys a certain amount of cotton forward.

As the number of revolutions increases, the amount of cotton being conveyed also increases.

Therefore:

If the rotational speed n increases **twofold**, the throughput Q also increases **twofold**; this is called a **direct proportional relationship**.

Why do we need the relation $Q=Cn$?

Because the formation of the torque occurs through the following chain:

$M \rightarrow Q \rightarrow F \rightarrow M$

- rotational speed \rightarrow amount of cotton conveyed;
- amount of cotton \rightarrow resistance force;
- resistance force \rightarrow torque.

Thus, expressing the throughput as $Q=Cn$ makes it possible to directly relate the rotational speed of the

screw to the torque acting on the shaft, which is essential for analyzing the operating режим and selecting the electric motor power.

At this point, the rotational speed n “enters” the torque expression.

The relation $Q=Cn$ in a screw conveyor is explained by the fact that **each revolution of the screw conveys a certain volume of cotton**. Therefore, as the rotational speed increases, the throughput increases in **direct proportion**.

In other words, **the faster the screw rotates, the more cotton is conveyed**, which leads to an increase in the resistance force and, consequently, in the torque acting on the screw shaft.

As a result:

$$F(n) = C \cdot g \cdot \mu \cdot k \cdot n$$

Thus, the main resistance force is linearly dependent on the rotational speed.

The function $F(n)$ represents the sum of the following forces:

- resistance caused by the weight of the cotton mass;
- friction between cotton and the screw surface;
- friction between cotton and the inner wall of the conveyor casing;
- additional resistance arising from the moisture content and fibrous structure of the cotton.

That is,

$$F(n)$$

is the force that the screw must overcome in order to move the cotton axially along the conveyor.

Substituting into the torque formula:

$$M(n) = F(n) \cdot r$$

$$M(n) = C_1 \cdot g \cdot f \cdot k \cdot r \cdot n$$

This expression can be written in the following form:

$$M(n) = \alpha n$$

where:

$$\alpha = C \cdot g \cdot \mu \cdot k \cdot r$$

α – **linear resistance coefficient**.

It represents the resistance required for the **basic axial movement of cotton along the screw**.

It incorporates the effects of the **cotton mass**, the **friction between cotton and the screw surface**, the **friction between cotton and the conveyor casing**, the **geometric dimensions of the screw**, and, partially, the **moisture content of the cotton**.

“This term represents the torsional (twisting) moment arising from the primary displacement process of cotton.”

“As the rotational speed increases, the following phenomena occur inside the screw:

Centrifugal force. For an elemental mass of cotton:

$$F_c = m\omega^2 r$$

$$\omega = \frac{2\pi n}{60} \Rightarrow F_c \sim n^2$$

This force presses the cotton against the screw wall. An increase in contact pressure leads to an increase in the friction force:

$$F_{ishq, qo'sh} = \mu \cdot F_c \sim n^2$$

This additional friction also increases the torque on the screw shaft.

“ $F_{Additional\ friction}$ is the additional friction force that arises as a result of an increase in rotational speed, due to the stronger pressing of the cotton against the conveyor wall under the action of centrifugal force.”

Quadratic torque component

Torque resulting from additional friction:

$$M_2(n) = \beta n^2$$

Where:

$$\beta \sim \mu' \cdot \rho \cdot r^2$$

- β – the effect of high-speed compaction and centrifugal force.
- μ' – the coefficient of friction effect at high rotational speed (typically 0.04–0.05).

For industrial screw conveyors, β is typically:

$$\beta \approx 0.005\text{--}0.03 \text{ N}\cdot\text{m}/(\text{ayl}/\text{min})^2$$

0.015 – a representative average, safe, and realistic value.

To perform the graphical analysis, the coefficients α and β were taken within the typical ranges reported in

the literature for screw conveyors transporting cotton. These values were used to qualitatively analyze the behavior of the model.

This term represents the compaction and inter-fiber adhesion characteristic of undried cotton.

In any real mechanical system, the following are present:

- bearing friction;
- gearbox losses;
- structural resistances, which are independent of the load.

This component:

$$M_0 = \text{const}$$

is introduced as.

By summing all components, we obtain the final mathematical model:

$$M(n) = M_0 + \alpha n + \beta n^2$$

Bu yerda:

- M_0 – no-load torque (mechanical losses),
- αn – resistance associated with cotton conveying,
- βn^2 – effects of compaction and centrifugal force.

The above model encompasses all the main mechanical mechanisms of the undried cotton conveying process.

The torque is determined by the tangential force acting on the screw shaft and the screw radius. While the main resistance torque arising from the motion of undried cotton inside the screw is linearly dependent on the rotational speed, at higher speeds the compaction of the cotton and the effect of centrifugal force introduce an additional nonlinear component. As a result, the torque is expressed as a quadratic function of the rotational speed.

In a screw conveyor transporting undried cotton, an increase in rotational speed leads to greater compaction of the cotton and an intensification of friction forces. As a result, the driving motor shaft torque does not decrease but instead increases.

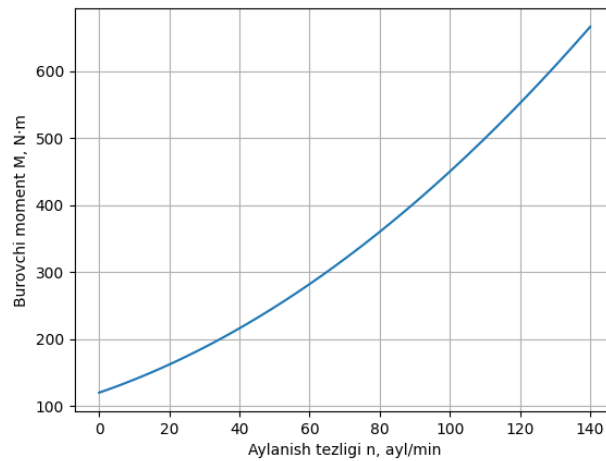


Figure 1. Dependence of torque on rotational speed.

As can be seen from the graph (Figure 1), in a screw conveyor transporting undried cotton, the torque increases nonlinearly with increasing rotational speed. At low speeds, the variation of torque is almost linear;

however, as the rotational speed increases, the rate of torque growth rises significantly. This behavior is explained by the intensification of cotton compaction and friction forces at higher speeds.

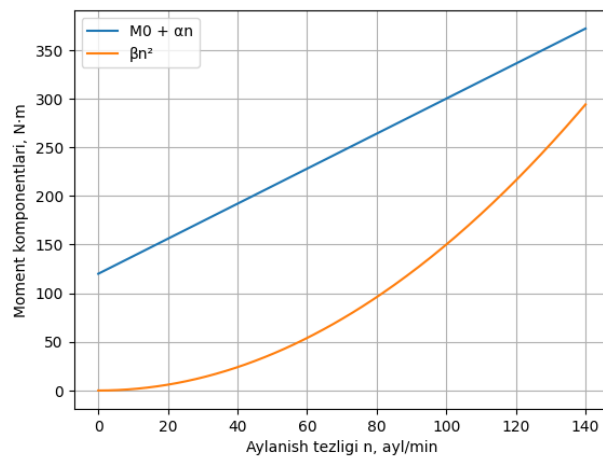


Figure 2. Dependence of torque components on rotational speed.

The analysis of the graph (Figure 2) shows that at low rotational speeds, the torque is mainly formed by the linear component. As the rotational speed increases, the contribution of the quadratic component grows and becomes dominant in the total torque at high speeds. This behavior is associated with the pressing of undried cotton against the conveyor wall under the action of centrifugal force and the emergence of additional friction forces. The linear term corresponds to simple cotton conveying, the quadratic term represents the effects of compaction and speed.

The graphs indicate that the dependence of torque on rotational speed in a screw conveyor is linear at low speeds and nonlinear at high speeds, with the quadratic component prevailing.

RESULTS

Dependence of Torque on Rotational Speed

As a result of the theoretical analysis, the torque acting on the screw conveyor shaft is expressed in the following general form.

$$M(n) = M_0 + \alpha n + \beta n^2$$

This expression indicates a nonlinear dependence of the torque on rotational speed. According to the model, as the rotational speed increases, the torque rises due to three main components: the no-load torque, the linear resistance torque, and the quadratic resistance torque.

Analysis of the low rotational speed regime

At low rotational speeds ($n \rightarrow 0$), the influence of the

quadratic term is very small, and the torque is mainly determined by the following expression:

$$M(n) \approx M_0 + \alpha n$$

In this case, the increase in torque is associated with the primary conveying of cotton along the screw, and the torque varies almost directly proportionally with the rotational speed. In this regime, the cotton does not undergo significant compaction inside the screw, the friction forces remain relatively stable, and the energy load of the conveyor is relatively low.

Operating regime at moderate rotational speeds

When the rotational speed reaches a certain range, the combined effect of the linear and quadratic terms becomes noticeable. In this regime, the cotton moves steadily inside the screw, the compaction process is limited, and the friction forces remain at a controllable level. The theoretical analysis indicates that it is precisely within this speed range that the rate of increase of torque is minimal.

This situation demonstrates the existence of an operating regime for the screw conveyor with maximum energy efficiency.

Analysis of the high rotational speed regime

As the rotational speed increases, the quadratic term (βn^2) becomes dominant, leading to a sharp rise in torque. This behavior is explained by the compaction of undried cotton inside the screw and its pressing against the conveyor casing wall under the action of centrifugal force.

At high speeds, due to the significant increase in friction forces, the motor shaft torque does not decrease; on the contrary, it increases. This results in higher electric motor loading, accelerated wear of mechanical components, and increased energy consumption.

Analysis of the torque growth rate

By differentiating the model, the rate of increase of the torque with respect to rotational speed is determined as follows:

$$\frac{dM}{dn} = \alpha + 2\beta n$$

This expression shows that as the rotational speed increases, the rate of torque growth also increases. This result theoretically substantiates the sharp rise in torque at high speeds and confirms that the screw conveyor has a limited optimal operating regime.

The theoretical calculations indicate that in a screw conveyor transporting undried cotton, the torque exhibits a nonlinear dependence on rotational speed. At low speeds, the torque variation is linear in nature, whereas at high speeds, compaction and friction effects become dominant. Therefore, selecting the optimal rotational speed of the screw conveyor is of great importance from both mechanical and energy-efficiency perspectives.

DISCUSSION

The results of the conducted theoretical analysis show that the operating process of a screw conveyor transporting undried cotton differs significantly from that of conveyors handling classical granular materials. The fibrous structure, high moisture content, and compressibility of cotton complicate the load characteristics on the screw conveyor shaft and lead to a nonlinear dependence of torque on rotational speed.

According to the proposed mathematical model, at low rotational speeds the variation of torque is mainly associated with the conveying of cotton along the screw, and an almost linear dependence of torque on speed is observed. This condition is characteristic of operating regimes in which the cotton is not significantly compacted inside the screw and the effect of centrifugal force is not yet dominant. In these regimes, the screw conveyor operates relatively steadily and energy consumption is minimal.

As the rotational speed increases, the contribution of the quadratic component in the torque composition grows. This behavior is explained by the pressing of undried cotton against the conveyor casing wall under the action of centrifugal force, the intensification of inter-fiber adhesion, and the increase in friction forces. As a result, the torque on the motor shaft rises sharply, and energy consumption increases significantly. This process is clearly reflected in the theoretical graphs, indicating a decrease in the energy efficiency of the screw conveyor at high rotational speeds.

The theoretical analysis shows that an excessive increase in rotational speed does not lead to a significant improvement in the productivity of the screw conveyor but instead results in increased mechanical loads and higher energy consumption. This may cause overloading of the electric motor, accelerated wear of mechanical components, and a

reduction in the operational reliability of the equipment. Therefore, when selecting the rotational speed of a screw conveyor, not only productivity but also variations in torque and energy consumption must be taken into account.

Although the results obtained in this study are based entirely on theoretical calculations, they have important practical significance for the design of screw conveyors and the selection of technological operating regimes. The proposed model makes it possible to justify the electric motor power, assess the strength of mechanical components, and determine the optimal rotational speed. At the same time, this theoretical approach can be further refined and extended through future experimental studies.

CONCLUSIONS

• **The dependence of torque on rotational speed in a screw conveyor transporting undried cotton was investigated based on comprehensive theoretical calculations, and this dependence was found to be nonlinear in nature. At low rotational speeds, the variation of torque follows an almost linear relationship; however, as the rotational speed increases, the torque rises sharply due to cotton compaction and increased friction forces.**

• The mathematical model $M_0 + \alpha n + \beta n^2$ describing the torque integrates, in a single expression, mechanical losses under no-load conditions, the primary cotton conveying process, as well as the effects of compaction and centrifugal force occurring at high rotational speeds. This model adequately reflects the physical nature of the undried cotton conveying process.

• The theoretical graphs and analyses demonstrate that an excessive increase in rotational speed does not lead to a significant improvement in the productivity of the screw conveyor, but instead results in a sharp increase in the motor shaft torque and energy consumption. This may cause excessive loading of mechanical components and a reduction in the operational reliability of the equipment.

• Based on the obtained results, the existence of an optimal rotational speed for the screw conveyor was theoretically substantiated. Within this speed range, the conveying of cotton along the screw proceeds steadily, the rate of torque growth is minimal, and high

energy efficiency of the conveyor is ensured.

• The proposed theoretical approach can be effectively applied at the design stage of screw conveyors to justify the electric motor power, assess the strength of mechanical components, and select technological operating regimes. This model serves as a scientific and methodological basis for improving transport mechanisms used for conveying undried cotton.

The results of this study demonstrate that increasing the rotational speed of a screw conveyor for transporting undried cotton is not always advisable and that the optimal speed should be selected on a theoretical basis.

REFERENCES

1. Djurayev A., Marasulov I. Vintli konveyerlar bo'yicha ilmiy izlanishlar tahlili. BuxMTI ilmiy jurnali. 6-2023.
2. А.Дж. Джуроев, К.К. Юлдашев, И.Р. Марасулов, А.И. Тохиров. Разработка эффективной конструктивной схемы винтового конвейера. АндМИ илмий-техник журнали. Махсус сон. №4. 2022.
3. Q. Holmirzayev. Tolali materiallarga birlamchi ishlov berish. O'quv qo'llanma. Toshkent. 2007.
4. Шукуров М.М. и др. Патент Рес. Узб. Винтовой конвейер. UZ IAP 032701, Бюлл. №2, 2007.
5. Абдугафаров Х.Ж. и др. Патент Рес. Узб. Винтовой конвейер. FAP №01141, Бюлл. №10, 2016.
6. Спиваковский А.О., Дьячков В.К. Транспортирующие машины. М.: Машгиз, 1983.