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ANALYSIS AND STUDY OF ROLLING PARAMETERS OF COILS ON AN INCLINED PLANE

Larysa Gumeniuk, Lesya Fedik, Volodymyr Didukh, Pavlo Humeniuk
Lutsk National Technical University, Lutsk, Ukraine

Abstract. *In the article, the patterns of movement of rolls of long-fiber plant crops on an inclined plane are investigated. Experimental data on determining the rolling time of rolls on an inclined plane with angles of inclination of 25° and 10° to the horizon for rolls of different mass and radius are processed. An analysis and investigation of the patterns of movement of these rolls have been carried out, including angular velocity, velocity of roll centers, rotation angle, and kinetic energy of the rolls.*

Keywords: data processing, rolling of rolls, optimization, computer graphics

ANALIZA I BADANIE PARAMETRÓW WALCOWANIA ZWOJÓW NA POCHYŁEJ PŁASZCZYŹNIE

Streszczenie. *W artykule zbadano wzorce ruchu zwojów roślin długowłóknistych na pochyłej płaszczyźnie. Przetworzono dane eksperymentalne dotyczące określania czasu walcowania zwojów na pochyłej płaszczyźnie o kątach nachylenia 25° i 10° do horyzontu dla zwojów o różnej masie i promieniu. Przeprowadzono analizę i badanie wzorców ruchu tych zwojów, w tym prędkości kątowej, prędkości środków zwojów, kąta obrotu i energii kinetycznej.*

Słowa kluczowe: przetwarzanie danych, walcowanie rolek, optymalizacja, grafika komputerowa

Introduction

In many industries, products derived from flax processing are utilized. Flax fiber is used in the textile industry and various other sectors, while flaxseed serves as a source of linseed oil and is also utilized in the food and feed industries. Several countries maintain robust flax industries focused on high-quality fibers. Ukraine is also a significant player in the global flax production market.

Standard practice in many agricultural regions where hay and flax are grown involves baling the raw materials in the field. This method offers numerous practical advantages, ranging from the simplicity of processing and transportation to improved preservation of quality and efficiency in harvesting and storage.

Baling hay and flax into compact rolls facilitates their handling and transportation. These rolls can be efficiently stacked and stored, reducing the area required for storage and transportation.

The baling of hay and flax into rolls helps preserve their quality by reducing the impact of moisture, sunlight, and other environmental factors. This protects the harvest from damage and ensures that it retains its nutritional value and fiber quality.

Baling hay and flax into rolls facilitates the drying process by increasing the surface area exposed to air. This helps to more effectively remove excess moisture, reducing the risk of spoilage and mold formation.

Baling hay and flax into rolls helps minimize losses during harvesting and storage. Compact rolls are less susceptible to damage from weather conditions, pests, and wildlife, reducing the risk of crop loss.

Rolls are often used in mechanized harvesting, where specialized machinery can efficiently collect and process crops in the field. This mechanization increases harvesting efficiency and reduces labor costs.

Research on the rolling processes of cylindrical rolls has been the subject of several studies. Physical testing of particle materiality parameters and contact parameters is described in [2] to provide data for simulation tests for the study of rolling friction. In [3], the deformation of segmented crop stems during harvesting was studied to optimize agricultural machinery. Work [1] is dedicated to studying the rolling processes of cylinders on inclined planes at different angles. However, the transportation and drying processes of cylindrical rolls of hay and flax have specific features due to their physical and technological properties. Therefore, they require separate consideration.

1. Problem statement

The technological process of hay and flax processing includes the operation of drying rolls, typically formed in the field in cylindrical shape. The rolls are unwound into a strip at factories with a thickness of 4 – 5 cm, after which they are blown through with a drying agent. This drying method leads to a decrease in the efficiency of the dryer due to the incomplete utilization of the maximum potential of the drying agent. Therefore, drying the raw material with high initial moisture content is carried out in rolls before unwinding them. Such drying is the most common, but the operations of installing rolls require additional mechanisms, complicating the dryer's design, which leads to significant energy consumption.

Learning about the process and means of drying flax fibers in rolls enables the optimization of production processes. Efficient drying methods are essential for preserving fiber quality, preventing mold and degradation, and ensuring consistency in manufacturing.

During the drying process in multi-section dryers, the transition of rolls from one section to another occurs by rolling the rolls along an inclined plane on which the drying sections are located.

The aim of the study is to investigate the patterns of movement of rolls along an inclined plane during the drying process of rolls of agricultural crops.

2. Research methods

The scheme of the rolling process along the inclined plane is shown in figure 1.

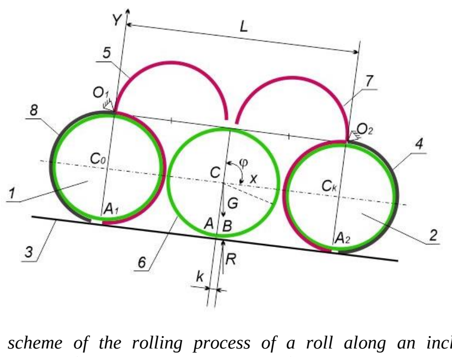

Fig. 1. The scheme of the rolling process of a roll along an inclined plane: 1 – starting position of the roll, 2 – end position of the roll, 3 – rolling surface, 4, 5, 7, 8 – movable semi-sections, 6 – roll

Semi-sections *5* and *7* rotate around axes O_1 and O_2. When semi-section *5* rises to the upper position and *8* remains lowered, roll *6*, under the action of its own weight, rolls along surface *3* from position *1* to position *2*. At the same time, semi-section *4* is closed, and *7* is raised. After receiving the roll, semi-section *7* is lowers, and the drying process continues.

During the design of the mechanism and organization of the drying process, it is necessary to determine the roll rolling law, the time of transition from one section to another, the kinetic energy of the roll at the end of the transition, and the load on the semi-section during the stop of the roll.

The calculation was carried out under the following assumptions:

1) the air resistance to the movement of the roll is negligible and can be disregarded;
2) the roll is securely bound, so during its rolling on the inclined plane, it does not come untied or change its volume (i.e., behaves as a rigid body).

Let's denote the center of the roll as *C*, then the initial position of *C* will be C_0 (the position of the roll in section *1*), and the final position of point *C* will be C_k (the position of the roll in section *2*). Let's draw axes *X* and *Y* through the center C_0 in such a way that the *X*-axis is directed in the direction of the center *C* movement, and the *Y*-axis is perpendicular upwards. Let φ denote the angle of rotation of the roll relative to the axis C_0O_1, considering it positive when directed clockwise. The roll undergoes planar-parallel motion, so we can use the differential equations of planar-parallel motion of a rigid body.

The roll is subjected to the force of gravity, *G*, and the rolling resistance force, *R*. The force *G* equals $m_r g$, where m_r is the mass of the roll in kilograms, and *g* is the acceleration due to gravity in meters per second squared.

The force *R* is the resultant of the vertical and horizontal components of the reaction of the inclined plane. According to [4], during the rolling of the cylinder along the base, the force *R* acts along the line of contact at a certain point *B*, which is located at a distance *k* from point *A*, the intersection of the cylinder axis with this base, where *k* is the coefficient of rolling friction measured in length units. Rolling of the cylinder without slipping along the base occurs when there is a smaller acting force. If we assume that the roll will move under the action of a force smaller in magnitude, then point *A* will be the instantaneous center of rotation during the roll.

The process of rolling rolls on an inclined plane is characterized by changes in the velocity of the rolling centers as well as the accumulation of kinetic energy during their displacement.

Based on the purpose of the study, tasks were set to establish the relationship between the change in velocity during the movement of rolls at an angle of inclination of the plane to the horizon and to determine the time of rolling and the change in the magnitude of kinetic energy of the rolls based on the length and angle of inclination of the inclined plane to the horizon.

The research was conducted according to standard methodologies [5] as well as proprietary methodologies developed by the authors.

The rolling process of the roll was carried out to determine the movement regularities from one section of the drying chamber to another. Roll *1* (Fig. 2) was placed on the inclined plane *2*, where a centimeter strip was fixed to establish the path of the roll's movement.

The rolling time of the roll from one section to another was determined using a stopwatch as the time from the start of rolling to the moment the roll hits a rigidly fixed vertical plane 3, made of metal.

For further calculations, the arithmetic mean of ten repetitions was taken.

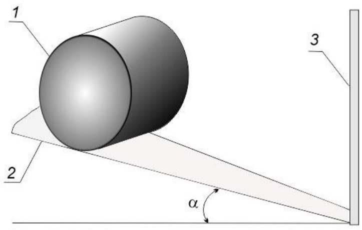

Fig. 2. The process of rolling a bale on an inclined plane: 1 – roll, 2 – rolling surface, 3 – vertical plane

3. Research results

The investigation of the rolling process of the roll was conducted at angles of 25° and 10° to the horizon, on a metal-painted surface. The experimental determination of the rolling time of rolls of different diameters and masses is presented in table 1.

Table 1. The results of determining the rolling time of rolls on an inclined plane

Inclination angle of the plane α, °	Roll radius r, m	Roll mass m, kg	Rolling time t, sec at l, m			
			1.2	2.2	3.2	4.2
25	0.50	187	0.8	1.0	1.2	1.4
	0.55	198	0.8	1.0	1.2	1.4
	0.60	219	0.8	1.1	1.2	1.4
10	0.50	187	1.6	1.8	2.2	2.6
	0.55	198	1.6	2.2	2.4	2.6
	0.60	219	1.6	2.0	2.4	2.6

To investigate the angular velocity of the rolls during rolling, the velocity of the roll centers during rolling, and the angle of rotation of the rolls, corresponding formulas were derived. The results of determining the parameters of the rolling process of rolls on an inclined plane are presented in table 2.

Table 1. The results of determining the parameters of the rolling process of rolls on an inclined plane

Inclination angle of the plane α, °	Roll radius r, m	Rolling time t, sec	Angular velocity φ, sec^{-1}	Roll centers velocity $\dot{x}_c$, m/sec	Roll turning angle φ, °
25	0.50	0.8	9.74	4.80	3.90
		1.0	12.28	6.19	6.09
		1.2	14.41	7.21	8.77
		1.4	17.05	8.72	11.94
	0.55	0.8	8.27	4.66	3.39
		1.0	10.58	5.82	5.29
		1.2	12.70	7.11	7.62
		1.4	14.82	8.15	10.37
	0.60	0.8	7.73	4.52	3.01
		1.0	9.42	5.63	4.71
		1.2	10.93	6.74	6.78
		1.4	13.02	7.81	9.23
10	0.50	1.6	3.85	1.93	2.70
		1.8	4.95	2.31	4.46
		2.2	6.11	2.88	6.66
		2.6	7.16	3.58	9.30
	0.55	1.6	4.00	2.17	3.07
		2.2	4.78	2.90	5.80
		2.4	5.13	3.16	6.90
		2.6	6.93	3.52	8.10
	0.60	1.6	2.98	1.19	2.09
		2.0	4.22	2.56	4.26
		2.4	5.22	3.06	6.13
		2.6	5.44	3.32	7.20

Based on the research results, graphs were constructed, presented in figures 3-5.

Figure 3 illustrates the curves of changes in angular velocity (φ) in sec^{-1} at different radii of rolls *r* and angles of inclination of the surface *α* over time.

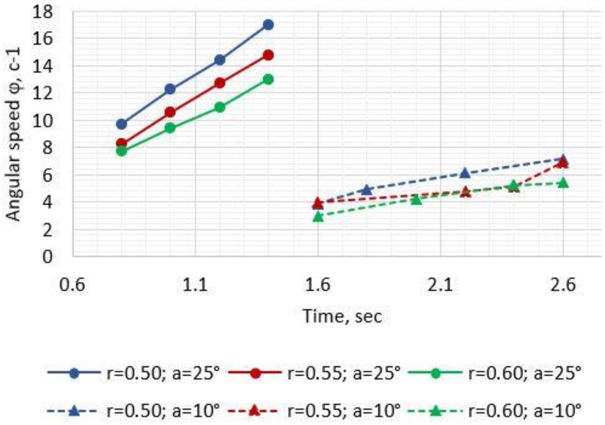

Fig. 3. Changing the angular speed of the rolls

Using the method of least squares, regression coefficients were calculated. It was determined that for a roll radius of 0.50 m and an incline angle of 25°, the angular velocity increases by approximately 3.2° per second, while for an incline angle of 10°, it increases by approximately 0.7° per second. For a roll radius of 0.55 m and an incline angle of 25°, the angular velocity increases by approximately 2.6° per second, whereas for an incline angle of 10°, it increases by approximately 0.9° per second. For a roll radius of 0.60 m and an incline angle of 25°, the angular velocity increases by approximately 2.2° per second, while for an incline angle of 10°, it increases by approximately 1° per second.

Changes in angular velocity can affect the uniformity of material processing. For instance, if the roll velocity changes unevenly or deviates from the expected pattern, it may lead to uneven material processing and, consequently, unacceptable product quality. Uneven velocity or sudden velocity changes can cause vibrations or other instabilities in the system, which may result in wear issues or even accidents.

Figure 4 illustrates curves showing the change in roll center velocity ($\dot{x}_c$) in meters per second (m/sec) for different roll radii and surface incline angles over time.

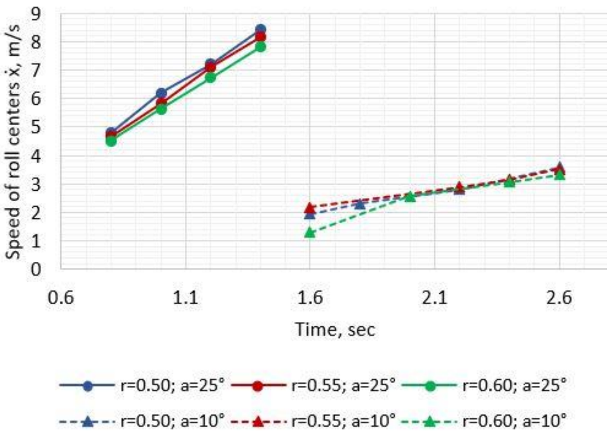

Fig. 4. Change the speed of the roll centers

The investigation of roll center velocities revealed the relationship between the rates of change in roll velocities over time. For a roll radius of 0.50 m and an incline angle of 25°, the increase in roll velocity is approximately 1.6 meters per second, while for an incline angle of 10°, it is 0.7 meters per second. For a roll radius of 0.55 m and an incline angle of 25°, the increase in roll velocity is approximately 1.06 meters per second, whereas for an incline angle of 10°, it is 0.9 meters per second.

Similarly, for a roll radius of 0.60 m and an incline angle of 25°, the increase in roll velocity is also approximately 1.06 meters per second, and for an incline angle of 10°, it is 0.9 meters per second.

The variation in roll center velocities during rolling can significantly impact the efficiency, quality, and safety of the drying process. Increasing the roll center velocities can accelerate the rolling process and consequently enhance productivity. However, it is essential to carefully control the velocity to avoid inadequate processing. The optimal rolling velocity can affect the quality of the resulting product. For instance, excessive velocity may lead to uneven drying, thereby reducing product quality.

Figure 5 illustrates curves depicting the change in roll turning angle (φ, °) for various roll radii and surface incline angles over time.

The change in the inclination angle of the surface, as well as the radius and mass of the rolls, also leads to a variation in the roll turning angle. For a roll radius of 0.50 m and an incline angle of 25°, the roll turns approximately by 3°, while for an incline angle of 10°, it turns by 2°. For a roll radius of 0.55 m and an incline angle of 25°, the roll turns approximately by 3.3°, whereas for an incline angle of 10°, it turns by 1.6°. For a roll radius of 0.60 m and an incline angle of 25°, the roll turns approximately by 2.4°, and for an incline angle of 10°, it turns by 1.5°.

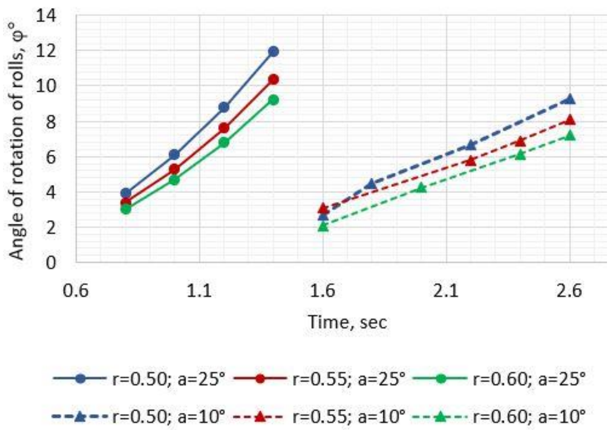

Fig. 5. Change the angle of rotation of the rolls

Analysis of the change in roll turning angle is necessary for understanding and influencing several aspects during the rolling of rolls on an inclined plane. The turning angle can determine the direction of roll movement. For instance, during drying or transportation processes, proper control of the turning angle can ensure efficient movement direction. During rolling, the turning angle can affect how loads are distributed on the roll surfaces. Optimal load distribution can prevent deformation or wear of the rolls. Proper control of the turning angle can ensure stability during rolling and influence roll maneuverability.

Since the investigation was conducted for rolling rolls on an inclined plane in multi-section dryers, these rolls acquire some kinetic energy during rolling, which can lead to unwanted situations. Calculating the kinetic energy allows assessing potential risks and taking necessary safety measures. The kinetic energy of the rolls also affects the mechanical load on the equipment used in multi-section dryers, so calculating it helps manage the rolling process. High kinetic energy of the rolls can lead to wear and degradation of materials used for their manufacture, such as hay or flax rolls. Calculation helps assess these risks and take measures to reduce them.

Figure 6 illustrates the change in kinetic energy ($K*10^3$, kJ) for various roll masses and surface incline angles.

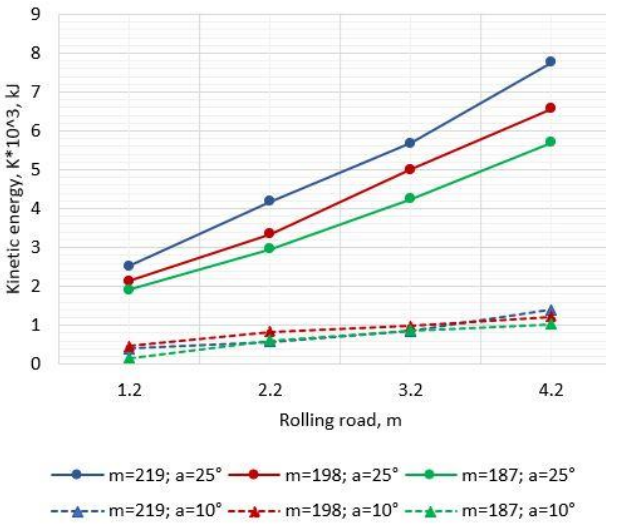

Fig. 6. Changes in the kinetic energy of the rolls

The change in the kinetic energy of agricultural crop rolls, as expected, varies in intensity depending on the incline angle of the rolling surface. At an inclination angle of 25°, the kinetic energy difference exceeds 5 kJ, whereas at an inclination angle of 10°, it is less than 1 kJ.

A comparative analysis of the investigated dependencies allows concluding that the optimal incline angle for transitioning raw material rolls from one section to another in multi-section dryers is $\alpha = 10°$.

4. Conclusion

Based on the data analysis, the following conclusions can be drawn. Analyzing the angular velocity and rolling speed of the rolls can help optimize the drying process. Adjusting these parameters can ensure the necessary drying conditions are met, leading to more efficient drying and potentially reducing drying time. The turning angle of the rolls also affects the uniformity of drying, ensuring proper treatment for each side of the roll, resulting in even drying and preserving the quality of hay or flax. Analyzing the kinetic energy of the rolls provides insight into potential instabilities in the system that could lead to equipment wear problems. By optimizing this parameter, equipment vibrations can be reduced, stabilizing its operation and ensuring reliable and durable equipment performance. Understanding the investigated parameters allows better control and optimization of the process. By analyzing roll parameters, it can be ensured that the drying process remains within specified parameters, leading to stable and reliable production results.

Thus, the analysis of experimental and calculated data on the angular velocity of rolls during rolling, the center velocity of rolls during rolling, the turning angle of rolls, and the kinetic energy of rolls during rolling on an inclined plane at incline angles of 25° and 10° has been performed. It is substantiated that the considered parameters can impact the quality of raw material processing and equipment stability. It has been found that the recommended optimal inclination angle of the rolling surface in multi-section dryers for agricultural crop rolls is 10°.

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Ph.D. Larysa Gumeniuk
e-mail: l.gumeniuk@lntu.edu.ua

Lutsk National Technical University, PhD. (technical), Department of Automation and Computer-Integrated Technologies.
Research interests: modeling of reliability and safety of the automated control systems.

https://orcid.org/0000-0002-7678-7060

Ph.D. Lesya Fedik
e-mail: fedikltsia@gmail.com

Lutsk National Technical University, PhD. (technical), Department of Automation and Computer-Integrated Technologies.
Research interests: computer and information technologies and automation of production processes.

https://orcid.org/0000-0001-7505-3789

Dr. Volodymyr Didukh
e-mail: didukh_v@ukr.net

Lutsk National Technical University, Dr. (technical), Professor Hailis Chair of Agricultural Engineering.
Research interests: organic farming, flax revival, agricultural engineering.

https://orcid.org/0000-0002-7358-7709

Ph.D. Pavlo Humeniuk
e-mail: p.gumeniuk@lntu.edu.ua

Lutsk National Technical University, PhD. (technical), Department of Automation and Computer-Integrated Technologies.
Research interests: programming, robotics.

https://orcid.org/0000-0002-6251-8548