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DISK TYPE FEED DEVICE OF AGRICULTURAL MACHINERY SIMULATION

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ABSTRACT

The article contains a mathematical model of the operation of disc-type feeders of agricultural machines. These mechanisms are designed to move and feed technological material into the working zone. The relevance of the study is due to the need to increase the efficiency, reliability and resource saving of machines. This is achieved by substantiating their design and operating parameters at the design stage. The purpose of the work is to develop an approach to the formation of mathematical models of disc feeders. Here, the working elements have the shape of cylinders and interact with the surface of the disk. A numerical experiment was conducted on the example of a feeder device of the mechanism for feeding corn cobs to the cutting zone.

To build a mathematical model, a generalized coordinate system and Lagrange equations of the second kind were used. The body motion is represented as the rolling of a cylindrical material particle along a concave surface without slipping. Rotational motion is taken into account. Numerical modeling was performed using the Model Vision Studio 3.2. Based on the results of the numerical experiment, rational parameters of the mechanism were established. The results obtained can be used to substantiate the design and kinematic parameters of the feeding devices of agricultural machines and their further improvement. The proposed approach to simulation creates the possibility of conducting virtual research without manufacturing a significant number of physical samples.

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МОДЕЛЮВАННЯ РОБОТИ ЖИВИЛЬНИХ АПАРАТІВ ДИСКОВОГО ТИПУ СІЛЬСЬКОГОСПОДАРСЬКИХ МАШИН

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АНОТАЦІЯ

Розглянуто питання математичного моделювання роботи живильних апаратів дискового типу сільськогосподарських машин, призначених для переміщення та подачі технологічного матеріалу в робочу зону. Актуальність дослідження зумовлена необхідністю підвищення ефективності, надійності та ресурсозбереження машин, шляхом обґрунтування їх конструктивних і режимних параметрів на етапі проектування. Метою роботи є розроблення підходу до формування математичних моделей дискових живильних апаратів, у яких робочі елементи мають форму циліндрів і здійснюють взаємодію з поверхнею диска, а також проведення числового експерименту на прикладі живильного пристрою механізму подачі качанів кукурудзи до зони різання.

Для побудови математичної моделі використано узагальнену систему координат і рівняння Лагранжа другого роду. Рух тіла представлено як кочення циліндричної матеріальної частинки ввігнутою поверхнею без проковзування з урахуванням обертального руху. Числове моделювання виконано із застосуванням середовища Model Vision Studio 3.2. За результатами числового експерименту встановлено раціональні параметри досліджуваного механізму. Отримані результати можуть бути використані для обґрунтування конструктивних і кінематичних параметрів живильних апаратів сільськогосподарських машин та їх подальшого вдосконалення. Запропонований підхід до математичного моделювання створює можливість проведення віртуальних досліджень без виготовлення значної кількості фізичних зразків.

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STATE OF THE RESEARCH PROBLEM

Mathematical models and simulation are important for researching and improving agricultural processes. Simulation formalizes the relationships between technical, technological, natural-climatic and economic factors. This allows you to explain the course of the process and predict its results under different operating conditions.

Mathematical modeling is of particular importance for agricultural machinery and technological processes, because the final result is simultaneously influenced by a large number of factors. For example, during the operation of a potato planter, the quality of planting depends on factors, namely: speed of movement, frequency of planting device rotation, size and shape of tubers, parameters of the feeding mechanism, capacity of the hopper, etc. Experimental determination of the optimal combination of parameters requires a lot of time and resources. The mathematical model allows you to study such dependencies theoretically and determine the most rational operating modes.

An important advantage of mathematical models is the ability to predict the results of the technological process. Using the initial parameters, it is possible to assess the machine's productivity, fuel consumption, the quality of the technological operation, the uniformity of the material supply, the degree of its damage, etc. This is especially important for the design of new machines and the modernization of existing structures.

Mathematical models are used to optimize technological processes. Mathematical methods allow determining the following values of design and operating parameters for maximum productivity, minimum energy consumption. For example, for the feeding mechanism of a potato planter, the model can establish the relationship between the speed of movement of the planting device, the number of captured tubers and the distance between them in the row.

Simulation is used to study processes that are difficult or expensive to conduct experiments with. A mathematical model changes the values of factors over a wide range and estimates the possible result without manufacturing a large number of test specimens. A physical experiment does not lose its value, but is used to verify the adequacy of the model and refine its parameters.

The application of mathematical models in modern digital and automated agriculture is promising. Models can be used for decision support systems, automatic control of agricultural machinery, yield forecasting, determination of optimal timing of technological operations, and rational use of material and energy resources.

Thus, a mathematical model is a tool for virtual research of the agricultural process. Its presence allows you to establish relationships between process parameters, predict its results, find optimal operating modes and justify design solutions. Therefore, mathematical modeling is one of the important methods for increasing the efficiency, productivity, reliability and resource conservation of modern agricultural production.

Nowadays, many researchers of agricultural processes and machines use mathematical modeling apparatus *(Liu Jianjun,2012; Jian Sun et al., 2023; Ange-Lionel Toba et al., 2020; Bhavik Shah, 2026; J.C. Ascough II, et al., 2008; Pozhydayev, 2011; Dudarev I. &Kirchuk R., 2014; Vasylkovsky O. et al., 2016).* This is the basis of theoretical research of the machine being designed. In addition, the development of specialized software, mathematical packages help to form complex models and perform numerical experiments.

For example, it is proposed to develop a model of the feeding device of disk-shaped agricultural units used in seed drills and other machines.

The purpose is the study is to develop a methodology for forming mathematical models of agricultural machines that have the form of disks and roll one after another. To develop a methodology and perform a numerical experiment of process modeling on the example of a laboratory sample of a feeder for a corn cob cutting device.

MATERIALS AND METHODS

The object of the study was the process of moving and loading agricultural materials into the processing zone. The subject of the study is the regularities of the movement of cylindrical bodies along the surface of the disk of the feeder mechanism. The research included a review of literature sources. Based on the analysis of the research, the main types of mathematical models used to describe such processes were identified. Simulation process of created model is based on the model building methodology proposed by *Petr Vasylenko (1960,1980,1990)*. The mathematical apparatus was based on the use of a generalized coordinate system and

the Lagrange's equations of the second kind. The numerical experiment was performed using the software product Model Vision Studium 3.2.

RESULTS OF THE STUDY AND DISCUSSION

The feeding mechanisms of agricultural machines are designed to collect, dose and evenly feed technological material from a hopper or storage tank to the actuator. In potato planters, the feeding mechanism captures individual tubers from the hopper and feeds them to the opener at the required frequency.

In a typical potato planter (**Fig. 1**), tubers are loaded into a hopper and then into a feeding mechanism. Its main task is to separate the tubers from each other and form a uniform flow of planting material. Chain conveyor, spoon, bucket, disc or belt feeding mechanisms are most often used. The design depends on the type of potato planter, the method of dosing and the required planting rate.

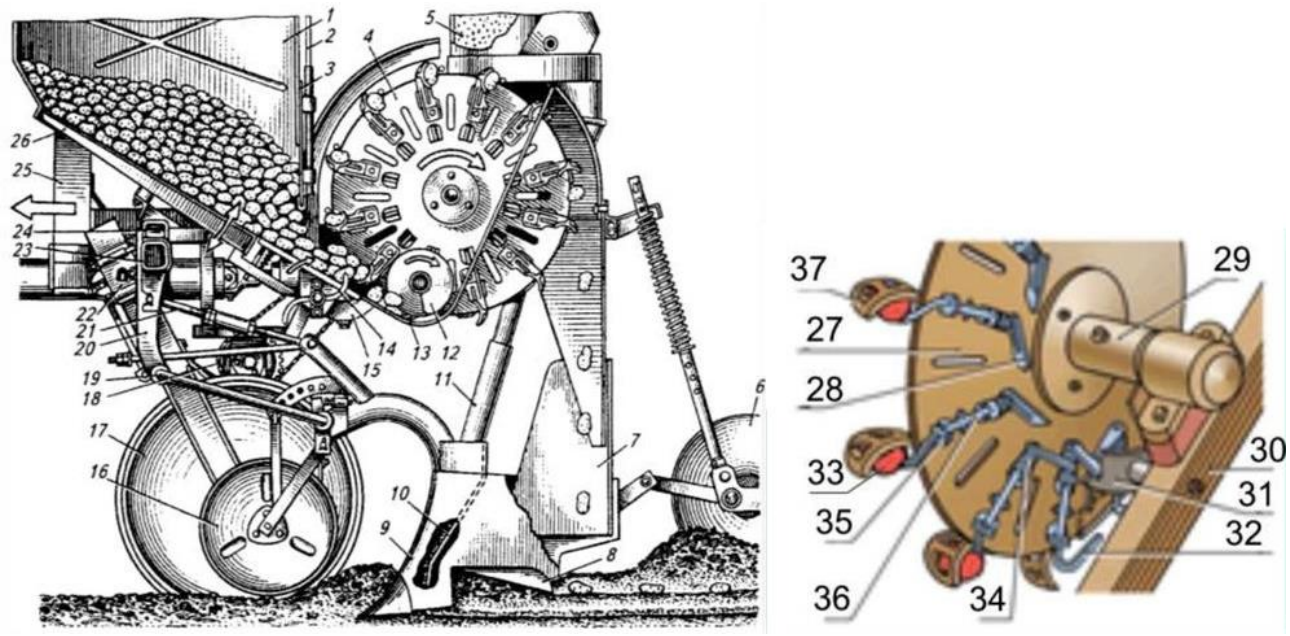


Fig.1 - Potato planter СН-4Б:
1- load hopper, 2- side frame, 3- gate, 4- side-frame device, 5- fertilizer distributor, 6- thorough disk, 7- canal bridge, 8- muck, 9- furrow-opener, 10- spreader plate, 11- fertilizer tube, 12- screw conveyer, 13- feeding bucket, 14- activator, 15- reducer, 16- gauge-wheel, 17- fifth wheel, 18- counter drive, 19- lower link, 20- console, 21- upper drawbar, 22- support wheel stand, 23-support wheel timber, 24- frame support timber, 25- hitch, 26-shaker, 27-disk, 28- clamping shank, 29- shaft, 30- frame, 31- guiding device, 32- clamping spindle,33- potato tuber, 34- spring, 35- fixed member, 36- clamp, 37- spoon.

The main requirements for feeding mechanisms are that the mechanism must ensure:
- uniform supply of planting material;
- minimal damage to tubers;
- reliable separation of individual tubers;
- stable operation with different sizes and shapes of tubers;
- the ability to adjust the planting rate;
- minimal clogging of the mechanism;
- coordination of the speed of movement of the feeding organ with the speed of movement of the unit.

A similar principle is used not only in potato planters. In agricultural machines, screw, belt, scraper, chain, coil, honeycomb, disc and pneumatic feeding mechanisms are used.

For example, in grain seeders, the coil mechanism doses seeds from the hopper, in pneumatic seeders, the seeds are selected by vacuum or excess pressure, and in fertilizer spreaders, the feeding mechanism provides fertilizer supply to the spreading body.

Thus, the feeding mechanism is an intermediate link between the hopper and the working body of the machine. Its design largely determines the uniformity of the technological process, the productivity of the machine and the quality of the operation.

Effective energy-saving drying technology requires the use of mechanical process intensification systems. Such systems require the modernization of drying complexes. Plant raw materials have specific characteristics, and therefore these mechanisms allow: to loosen and mix the grain layer, increase the contact area of the drying agent with the wet material, direct the flows of the drying agent, etc.

One way to reduce energy consumption for post-harvest processing is to increase the contact area between the surface of the material and the drying agent (*Panasyuk S. (2008)*). For corn, this is done by dividing the cob into parts (**Fig. 2**). For legumes, such as soybeans, this effect is achieved by scoring the surface of the grain (**Fig. 3**) before loading into the dryer (*Kopets K. (2016)*).

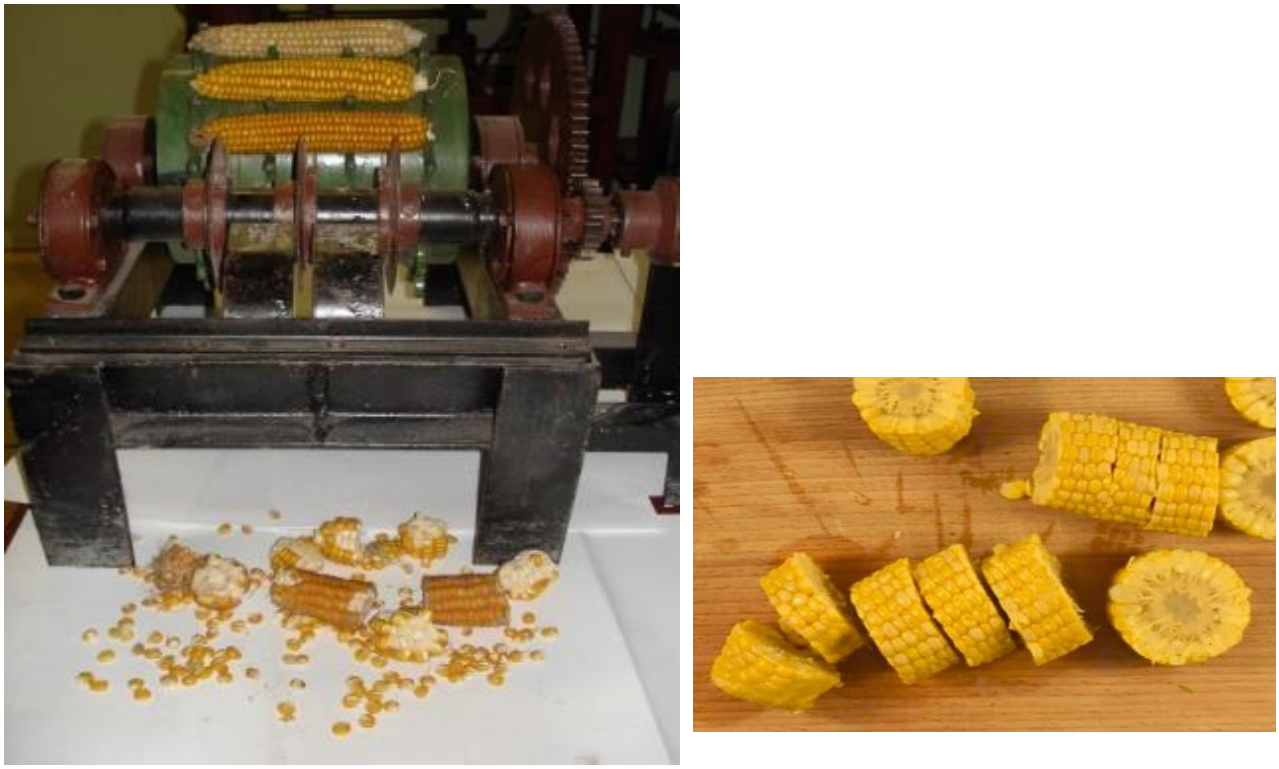


Fig.2 – Corn cob crushing mechanism



Fig.3 – Mechanism of cutting soybean hulls

The movement of the cob can be represented as a set of translational motions around point *O*. Here, the motion occurs with angular velocity ω and relative motion, which is the rolling of the cylinder with rotational velocity Ω by a concave cylindrical holding surface. The angular velocity of the drum rotation ω is insignificant, so the force of inertia can be neglected.

As a result, with an accuracy acceptable for engineering calculations, the movement of the cob can be considered as the rolling of a cylindrical particle with radius r and mass m along a concave cylindrical surface with radius R. In turn, the cylindrical surface rotates around the point O with angular velocity ω. In the proposed model, this is taken into account by changing the angles of application of forces to the cylindrical particle (cob) with time.

To solve the problem, the following assumptions must be made:

- the cob is considered as a cylindrical material particle with a rough surface;
- the material particle during the rotation from position *A* to position *B* moves by rolling without slipping along the concave cylindrical surface;
- the feed drum rotates with a constant angular velocity ω;
- the movement of the cob begins from a rest position at point A_1.

The following forces act on a material particle: the weight of the particle $P = mg$, the normal pressure force to the particle from the side of the cylindrical surface N, the friction force T.

The system of differential equations describing the motion of the cob will have the form:

$$m(R-r)\ddot{\varphi} = -P\sin(\varphi - \omega t) - T, \tag{1}$$

$$m(R-r)\dot{\varphi}^2 = N - P\cos(\varphi - \omega t), \tag{2}$$

$$m\rho^2\ddot{\Omega} = Tr, \tag{3}$$

where Ω - the angle of rotation of the head relative to its own axis of rotation;

φ - the angle by which the plane passing through the center of mass of the particle point O_k and the axis of rotation of the imaginary cylinder point O_1 deviates;

ωt - angle of rotation of the feed cylinder around the point *O*;

ρ - radius of inertia of the cylinder.

In this case $\rho = \frac{r}{\sqrt{2}}$.

Since a cylindrical particle rolls on a cylindrical surface without slipping, we can write:

$$\Omega r = \varphi R. \tag{4}$$

Where

$$\varphi = \frac{r}{R}\Omega. \tag{5}$$

From equation (3) we obtain the expression for the friction force:

$$T = \frac{m\rho^2\ddot{\Omega}}{r}. \tag{6}$$

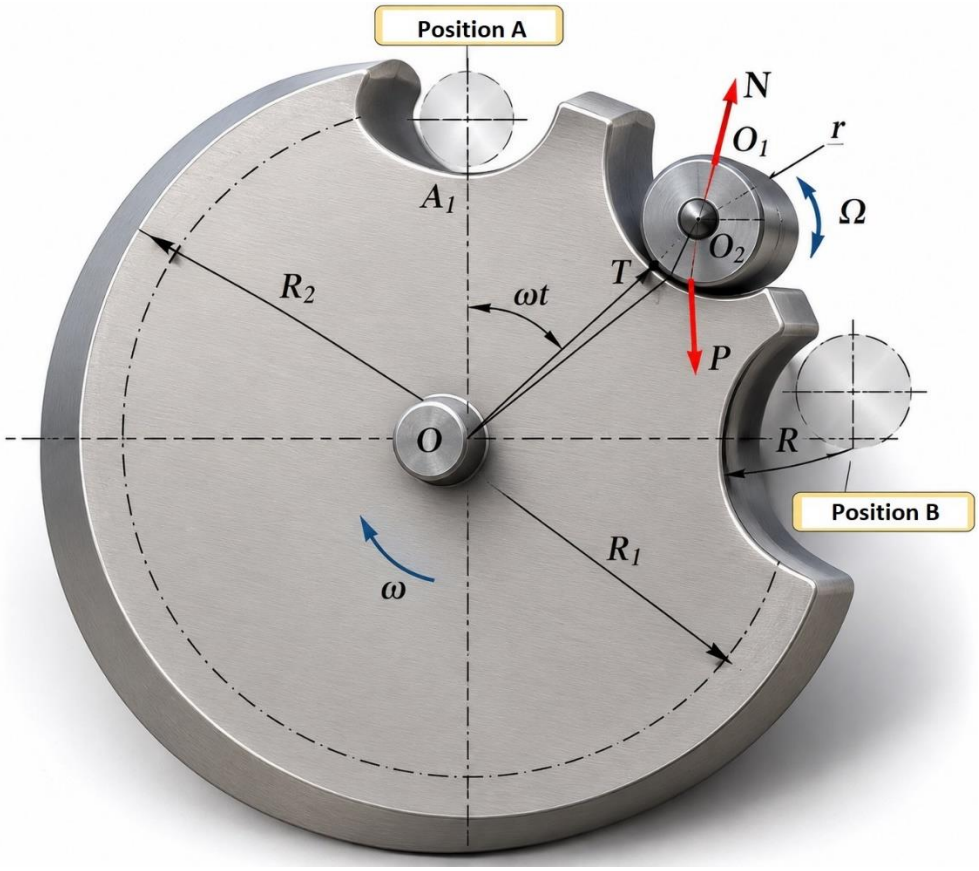


Fig.4 - Calculation scheme of movement

Substituting expressions (5) and (6) into (3), we obtain:

$$m\left(R-r\right)\frac{r}{R}\ddot{\Omega}=-P\sin\left(\frac{r}{R}\Omega-\omega t\right)-\frac{m\rho^2\ddot{\Omega}}{r}. \tag{7}$$

From equation (7) we have:

$$\ddot{\Omega}=-P\sin\left(\frac{r}{R}\Omega-\omega t\right)-\left[m\left(R-r\right)\frac{r}{R}+\frac{m\rho^2}{r}\right],$$

or

$$\frac{d^2\Omega}{dt^2}=-P\sin\left(\frac{r}{R}\Omega-\omega t\right)-m\left[\left(R-r\right)\frac{r}{R}+\frac{r}{2}\right]. \tag{8}$$

The solution of equation (8) allows us to conduct a kinematic analysis of the mechanism as a whole by interrelating the determining parameters of the mechanism. These parameters are the radii R, R_1,R_2 and the angular velocity of rotation of the drum ω.

It is advisable to solve equation (8) and analyze the parameters of the mechanism by setting up and conducting a numerical experiment. The numerical experiment is based on the use of numerical methods for solving the proposed mathematical model and visualizing the process.

Simulation can be carried out using the dynamic process modeling system Model Vision Studio 3.2. The result is the construction of graphs of the movement of the center of mass of the head relative to the axis of rotation of the feed drum point *O* and the formation of a video image of the movement of the head until it enters the processing zone. An example of the solution is shown in **Fig. 5**.

Analysis of the results of the numerical experiment, which can be represented by a system of graphs (**Fig. 6**, **Fig.7**), showed that the rational parameters of the mechanism are: angular rotation speed $\omega = 1.2\ s^{-1}$, diameter of the feed drum $D = 0.21$ m, diameter of the holding hole $d = 0.06$ m.

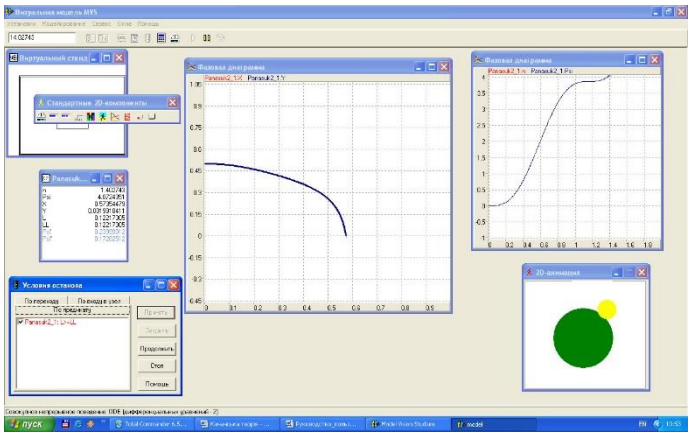


Fig.5 - Movement simulation of the head of corn by Model Vision Studio 3.2

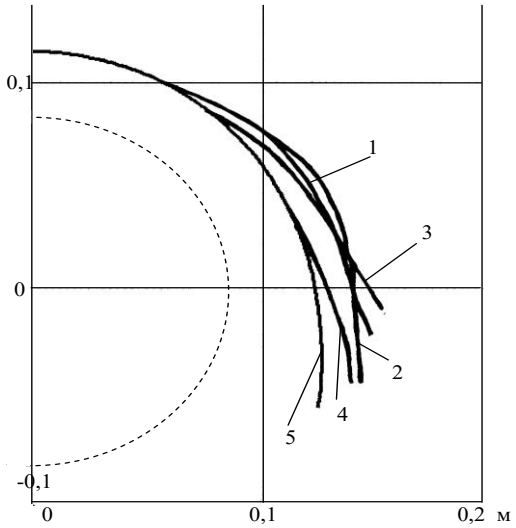


Fig.6 - The trajectory of the cylinder (cob) when feeding into the processing zone:
1) $\omega=0,1\ c^{-1}$;
2) $\omega=0,3\ c^{-1}$;
3) $\omega=0,6\ c^{-1}$;
4) $\omega=0,9\ c^{-1}$;
5) $\omega=1,2\ c^{-1}$.

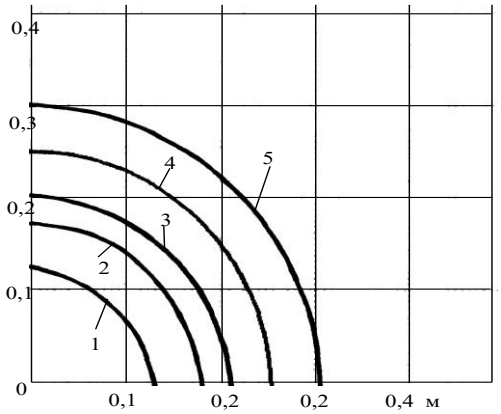


Fig.7 - The trajectory of the cylinder (cob) when feeding into the processing zone:
1) $R_1=0,12м$, $R=0,03м$;
2) $R_1=0,17м$, $R=0,05м$;
3) $R_1=0,20м$, $R=0,08м$;
4) $R_1=0,25м$, $R=0,10м$;
5) $R_1=0,30м$, $R=0,12м$.

CONCLUSIONS

The article reviews the basic mechanisms of feeding (feeding to the processing zone), which are a system of cylinders, and their scope of application. As a result of theoretical research and calculation using a mathematical model, rational parameters of the device for feeding corn cobs to the cutting zone were calculated. In the model, the movement of the cylinder (cob) is represented as the rolling of a cylindrical material particle along a concave cylindrical surface without slipping, taking into account the rotational motion of the feeding drum. Numerical modeling of the cob movement was carried out and the influence of the angular velocity of the feeding drum and the geometric parameters of the device on the trajectory of the cob movement in the direction of the cutting zone was investigated. The results obtained can be used when designing and improving the feeding devices of agricultural machines and units. The implementation of the proposed method of preparing the material creates technological prerequisites for the application of energy-saving technologies for its further processing. Further research should be directed at experimental verification of the obtained rational parameters and establishing their influence on the stability of the feeding mechanism and the quality and energy performance of the operation.

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