UDC 514.18 DOI 10.31548/ energiya3(67).2023.123

ERGONOMIC ASPECTS OF MODELING THE PROCESS OF MATERIAL SEPARATION ON STATIONARY SCREW SURFACES

S. F. Pylypaka, doctor of technical sciences, professor

A. V. Nesvidomin, Candidate of Technical Sciences, docent

National University of Life and Environmental Sciences of Ukraine

E-mail: a.nesvidomin@gmail.com

Abstract. *The movement of material particles along gravitational surfaces is used in special devices for their separation by physical and mechanical properties. For this, stationary helical surfaces of constant pitch are used. In the mining industry, screw separators with different axial cross-sections (chute) are used for the enrichment of ores. Grain separation is carried out on linear helical surfaces, which are compartments of an oblique helicoid. Despite the fact that such separators are passive working bodies and do not require energy to drive them, they also have disadvantages. This is relatively low performance and low resolution.*

Now the calculation of the relationship between the kinematic parameters of the movement, the coefficient of friction and the design parameters of the separator, as well as the case when its surface is an expanding helicoid, has been carried out.

The purpose of the research is the analysis of a helical surface with various design parameters for the purpose of improving its resolution using mathematical and geometric modeling of the process without the production of surface models.

Solving the problem of building the trajectory of the movement of a material particle along the surface under the action of its own weight is preceded by the problem of finding the trajectory on an inclined plane.

It is described by a system of equations, which is non-linear and numerical methods must be used for its integration. Modern software products make it possible not only to find the trajectory of a particle's movement, but also to show it on the surface and even make an animation, which essentially replaces high-speed photography. This approach makes it possible to study the kinematic parameters of movement on various helical surfaces without full-scale samples of these surfaces, which significantly reduces the cost of searching for the necessary surfaces.

The motion of a particle along a helical conoid and a spreading helicoid is considered. It has been established that the nature of the particle movement will also be different for different surfaces. When moving along the surface of a helical conoid, a particle first accelerates in the presence of friction, and then stops at a considerable distance from its axis. To prevent this, it is necessary to take a limited compartment of the conoid both in height and along its periphery. When a particle moves along the surface of an expanding helicoid, its speed becomes constant over time, and the trajectory after that will be a helical line.

In further research, it is necessary to use the developed approaches to identify the possibilities of material separation not only after the stabilization of the movement, but also during the transition process, since its visualization has become possible. This will make it possible to select a surface compartment of the optimal size, which will ensure the required separation performance due to the dispersion of particles with different friction coefficients on its surface.

Key words: ***mathematical modeling, trajectory of particle movement, speed of movement, helical conoid, unfolding helicoid***

Topicality. The movement of material particles along gravitational surfaces, that is, the movement of particles along surfaces under the influence of their own weight, is used in special devices for their separation by physical and mechanical properties. For this, stationary helical surfaces of constant pitch are used. In the mining industry, screw separators with a different shape of the axial section (trough) are used for the enrichment of ores [1]. Grain separation is carried out on linear helical surfaces, which are compartments of an oblique helicoid. After stabilization of the process, seeds with different friction coefficients move at constant speeds along helical lines at different distances from the axis of the helicoid. Despite the fact that such separators are passive working bodies and do not require energy to drive them, they also have disadvantages. This is relatively low performance and low resolution (a small difference in the trajectories of particles with different physical and mechanical properties) [2].

Analysis of recent research and publications. The calculation of the relationship between the kinematic parameters of movement, the coefficient of friction and the design parameters of the separator is carried out in works [3, 4]. The work [4] considered and made calculations for the separator in the case when its surface is an unfolding helicoid. The transition process to the stabilization of the movement of a particle on such a surface is considered in detail in the work [5].

The purpose of the article is investigate helical surfaces with different design parameters to improve their resolution using mathematical and geometric modeling of the process without making surface models.

Materials and methods of research. Solving the problem of constructing the trajectory of the movement of a material particle along the surface under the action of its own weight is preceded by the problem of finding the trajectory on an inclined plane. If a material particle hits an inclined plane with a certain initial speed v_o and a certain angle of inclination to the horizon, then it will move along a certain curve (in the absence of friction and air resistance, the trajectory will be a parabola). The centrifugal force caused by the curvature of the trajectory k always acts along the main normal of the curve in the opposite direction of its direction and is determined from the expression mv^2k, where m is the mass of the particle, v is its velocity. Since the trajectory on the plane is a flat curve, the vector of action of the centrifugal force is located in the plane of the curve. The vector of this force is included in the main equation of the dynamics of a point, $m\bar{a} = \bar{F}$, where m is the mass of the point (particle), $\bar{a}$ - the acceleration given to it by the equivalent forces applied to the point. $\bar{F}$. If we take the surface, then the vector of the centrifugal force must be decomposed into two mutually perpendicular components: one component $mv^2k \cdot \sin\varepsilon$ acts in the plane tangential to the surface perpendicular to the direction of movement, the other $mv^2k \cdot \cos\varepsilon$ - along the normal to the surface, increasing or decreasing the pressure on the surface, where ε is the angle between the normal to the surface and the main normal of the trajectory. , Expressions $k \cos\varepsilon = k_n$ and $k \sin\varepsilon = k_g$ in differential geometry are called the normal and geodesic curvature of the curve on the surface, respectively. Normal curvature is determined by the coefficients of the first and second quadratic forms, and geodesic curvature is determined by the coefficients of only the first quadratic form of the surface. If we write down the main equation of the dynamics of a point $m\bar{a} = \bar{F}$ in the projections onto the orthos of the accompanying Darboux trihedron of the trajectory, then it reduces to a system of differential equations (the derivation of these equations is shown in detail in the work [5]):

$$\begin{cases} v\dfrac{dv}{ds} = g\cos\psi - f(g\cos\omega + v^2k_н); \\ v^2k_г = g\cos\varphi, \end{cases} \qquad (1)$$

where f is the coefficient of friction; s is the length of the arc of the trajectory; $g = 9.81$ m/s^2 - Acceleration of gravity; ψ, φ, ω - the angles between the particle weight vector and each of the vertices of the trihedron.

System (1) does not include the mass of the particle m, since the equations were reduced to it (this is possible in the absence of other applied forces besides the weight force mg acting on the particle). System (1) describes the movement of a material point along a gravitational surface in the general case, while the angles ψ, φ, ω, velocity v, geodesic k_g and normal k_n curvature of the trajectory are functions of its arc s or another parameter that defines the curve on the surface. If the surface is given by parametric equations $X = X(\alpha, u)$; $Y = Y(\alpha, u)$; $Z = Z(\alpha, u)$, where α and u are independent variables, then solving system (1) means finding such a relationship between the variables α and u so that the conditions of this system are met at each point of the curve that will form on the surface with the found dependence.

If system (1) is drawn for a specific surface, then it will be nonlinear and numerical methods must be used for its integration. Modern software products make it possible not only to find the trajectory of a particle's movement, but also to show it on the surface and even make an animation, which essentially replaces high-speed photography. This approach makes it possible to study the kinematic parameters of movement on various helical surfaces without full-scale samples of these surfaces, which significantly reduces the cost of searching for the necessary surfaces. Take for example some helical surfaces.

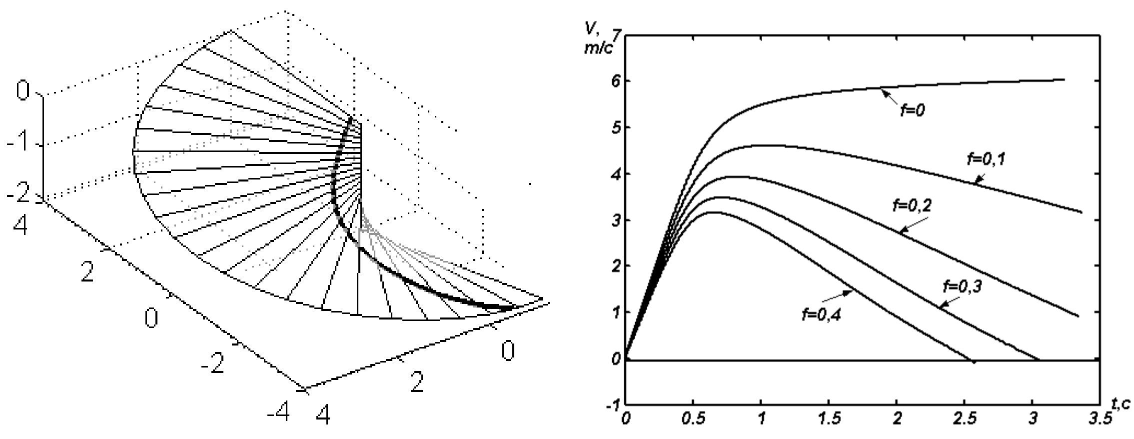
Research results and their discussion. For a helical conoid given by parametric equations:

$$X = u\cos\alpha; \qquad Y = u\sin\alpha; \qquad Z = b\alpha, \tag{2}$$

where b is a screw parameter (constant value), system (1) takes the form [6]

$$\begin{cases} v^2 \sin\beta\left(\text{th}w + \dfrac{d\beta}{d\alpha}\right) = bg\cos\beta; \\ \dfrac{v\sin\beta}{b}\dfrac{dv}{d\alpha} = g\sin\beta - f\left(v^2\dfrac{\sin 2\beta}{b\text{ch}w} + g\text{sh}w\right), \end{cases}$$

where $w = \int \text{ctg}\beta\, d\alpha.$ (3)



a *b*

Fig. 1. Graphic illustrations of the movement of a material particle on the surface of a helical conoid (helix parameter *b =0.6*):
a - trajectory of a particle from the start of movement to the moment of stopping;
b - dependences of changes in the velocity of particles with different friction coefficients

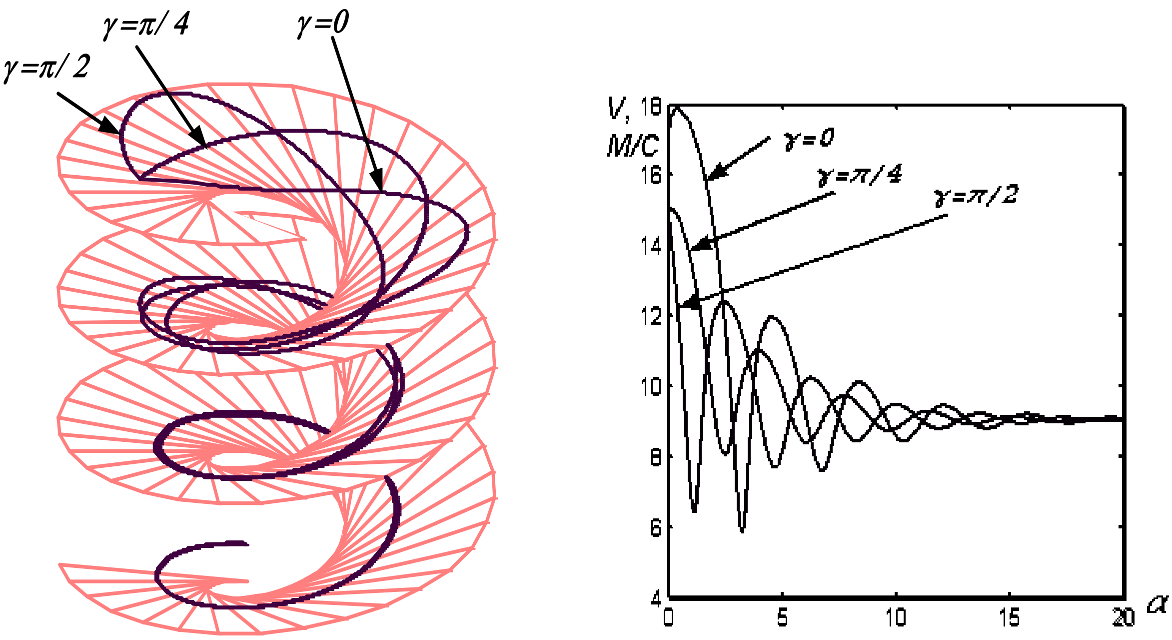
The solution of system (3) is two dependencies: particle speed $v = v(\alpha)$ and the angle $\beta = \beta(\alpha)$ between the generators of the conoid and the trajectory of motion. The integration of the system showed that the particle, starting its movement with an initial speed close to zero, first accelerates, moves away from the axis of the conoid and stops (Fig. 1a). This is explained by the fact that as it moves away from the axis of the conoid, the angle of inclination of the trajectory to the horizontal plane decreases and the moment comes when the particle can no longer overcome the force of friction. On the graph of the change in the speed of particle movement as a function of time (Fig. 1b), it can be seen that the particles with the highest friction coefficient stop the fastest. In the absence of friction and air resistance, the particle will not stop: its speed approaches a constant value over time.

For an expanding helicoid given by parametric equations:

$$X = R\cos\alpha + (R\alpha - u\cos\beta)\sin\alpha;$$
$$Y = R\sin\alpha - (R\alpha - u\cos\beta)\cos\alpha;$$
$$Z = u\sin\beta, \qquad (4)$$

where R is the radius of the cylinder on which the spiral line is located - the edge of the surface return (4), β- the angle of elevation of the spiral line, the system (1) takes the form [5]:

$$\begin{cases} v' = \dfrac{g}{v}u'\sin\beta - f\left[\dfrac{g}{v}\cos\beta\sqrt{u'^2 + (R\alpha - u\cos\beta)^2} + \dfrac{v\sin\beta(R\alpha - u\cos\beta)}{\sqrt{u'^2 + (R\alpha - u\cos\beta)^2}}\right]; \\ u'' = \dfrac{g}{v^2}\sin\beta\left[u'^2 + (R\alpha - u\cos\beta)^2\right] + u'\dfrac{R - 2u'\cos\beta}{R\alpha - u\cos\beta} - (R\alpha - u\cos\beta)\cos\beta. \end{cases} \quad (5)$$



a *b*

Fig. 2. The trajectories of the movement of a material particle and the corresponding velocity graphs under the same initial conditions *(* $\alpha_o = 0$, $u_o = 20$ *m*, $v_o = 15$ *m/s*, $f = 0.3$*)* and different directions at the beginning of the movement (γ - the angle between the direction of the vector of the initial speed and rectilinear generating surface)

The solution of system (5) is the dependencies $v = v(\alpha)$ and $u = u(\alpha)$. The first characterizes the change in speed, and the second establishes the relationship between the independent variables of the surface (4) and thereby sets the trajectory of the particle's movement on it. In fig. 2a shows a section of the unfolded helicoid surface and the trajectory of the particle, obtained as a result of the integration of system (5). From fig. 2, and it can be seen that after several revolutions the particles that started their movement in different directions on the surface move further along a common trajectory, which is a helical line. Their speed also stabilizes and becomes constant after approximately three revolutions ($\alpha \approx 20$ *rad.* according to Fig. 2b). After stabilization of the motion, that is, at $v = const$ and $\rho = const$, where ρ is the distance from the axis of the helicoid to the particle on the surface, it is possible to solve system (5) in elementary functions and determine the speed of movement *v of* the particle and the distance ρ depending on the structural parameters of the surface R and β, and the coefficient of friction f [5].

Conclusions and perspectives. Modeling of the movement of a material particle along helical surfaces and its research using modern means of numerical integration and visualization showed that the character of the movement of the particle will also be different for different surfaces. When moving along the surface of a helical conoid, a particle first accelerates in the presence of friction, and then stops at a considerable distance from its axis. To prevent this, it is necessary to take a limited compartment of the conoid both in height and along its periphery. When a particle moves along the surface of an expanding helicoid, its speed becomes constant over time, and the trajectory after that will be a helical line.

The prospects for further research are to use the developed approaches to reveal the possibilities of material separation not only after the stabilization of the movement, but also during the transition process, since its visualization has become possible. This will make it possible to select a surface compartment of the optimal size, which will ensure the required separation performance due to the dispersion of particles with different friction coefficients on its surface. At the same time, the developed approach will make it possible to simulate the movement of a particle on other helical surfaces (oblique closed helicoid, oblique open helicoid), as well as on helical surfaces with a variable pitch without making models of these surfaces.

List of references

1. Аникин М. Ф., Иванов В. Д., Певзнер М. Л. Винтовые сепараторы для обогащения руд. М.: Недра, 1970. 184 с.
2. Заика П. М., Мазнев Г. Е. Сепарация семян по комплексу физико-механических свойств. М.: Колос, 1978. 287 с.

3. Заика П. М. Избранные задачи земледельческой механики. К.: Изд-во УСХА, 1992. 507 с.

4. Сысоев Н. И**.** Теоретические основы и расчет сортировки “Змейка”. Сельхозмашина. 1949. № 8. С. 5 – 8.

5. Войтюк Д. Г., Пилипака С. Ф. Знаходження траєкторії руху матеріальної точки по гравітаційній розгортній поверхні на прикладі розгортного гелікоїда. Механізація і енергетика сільського господарства. IV міжнародна науково-технічна конференція MOTROL-2003. К.: НАУ, 2003. Т.6. С. 113-126.

6. Войтюк Д. Г., Пилипака С. Ф. Знаходження траєкторії руху матеріальної частинки по гравітаційних лінійчатих поверхнях із горизонтальними твірними. Збірник наукових праць НАУ “Механізація сільськогосподарського виробництва”. 2002. Т.12. С.58-69.

References

1. Anikin, M. F., Ivanov, V. D., Pevzner, M. L. (1970). Vintov·yye separatory dlya obogashcheniya rud [Screw separators for ore dressing]. Moskow: Nedra, 184.

2. Zaika, P. M., Maznev, G. E. (1978). Separatsiya semyan po kompleksu fiziko-mekhanicheskikh svoystv [Separation of seeds according to the complex of physical and mechanical properties]. Moskow: Kolos, 287.

3. Zaika, P. M. (1992). Izbrann·yye zadachi zemledel'cheskoy mekhaniki. [Selected tasks of agricultural mechanics]. Kyiv: Publishing House of USHA, 507.

4. Sysoev, N. Y. (1949). Teoreticheskiye osnovy i raschet sortirovki “Zmeyka" **[**Theoretical basis and calculation of sorting "Zmeyka"]. Selkhozmashina, 8, 5-8.

5. Voytiuk, D. G., Pylypaka, S. F. (2003). Znakhodzhennia traiektorii rukhu materialnoi tochky po hravitatsiinii rozghortnii poverkhni na prykladi rozghortnoho helikoida [Finding the trajectory of the movement of a material point along a gravitational unfolding surface on the example of an unfolding helicoid]. Mechanization and energy of agriculture. IV international scientific and technical conference MOTROL-2003. Kyiv: NAU, 2003, 6, 113-126.

6. Voytiuk, D. G., Pylypaka, S. F. (2002). Znakhodzhennia traiektorii rukhu materialnoi chastynky po hravitatsiinykh liniichatykh poverkhniakh iz horyzontalnymy tvirnymy [Finding the trajectory of the movement of a material particle along gravitational linear surfaces with horizontal generators Collection of scientific papers of NAU "Mechanization of agricultural production", 12, 58-69.

ЕРГОНОМІЧНІ АСПЕКТИ МОДЕЛЮВАННЯ ПРОЦЕСУ СЕПАРАЦІЇ МАТЕРІАЛУ НА СТАЦІОНАРНИХ ГВИНТОВИХ ПОВЕРХНЯХ

С. Ф. Пилипака, А. В. Несвідомін

Анотація. *Рух матеріальних частинок по гравітаційних поверхнях використовується у спеціальних пристроях для їх сепарації за фізико-механічними властивостями. Для цього застосовуються стаціонарні гвинтові поверхні сталого кроку. У гірськорудній промисловості для збагачення руд використовуються гвинтові сепаратори з різною формою осьового перерізу (жолоба). Сепарація зерна здійснюється на лінійчатих гвинтових поверхнях, якими є відсіки косого гелікоїда. Не дивлячись на те, що такі сепаратори є пасивними робочими органами і не*

потребують затрат енергії для їх приводу, вони мають і недоліки. Це порівняно невелика продуктивність і мала роздільна здатність.

Нині здійснений розрахунок взаємозв'язку між кінематичними параметрами руху, коефіцієнтом тертя і конструктивними параметрами сепаратора, а також випадку, коли його поверхня є розгортним гелікоїдом.

Метоюдослідження є аналіз гвинтової поверхні із різними конструктивними параметрами на предмет покращення її роздільної здатності за допомогою математичного і геометричного моделювання процесу без виготовлення моделей поверхонь.

Розв'язанню задачі побудови траєкторії руху матеріальної частинки по поверхні під дією сили власної ваги передує задача знаходження траєкторії на похилій площині.

Вона описується системою рівнянь, яка є нелінійною і для її інтегрування потрібно застосовувати чисельні методи. Сучасні програмні продукти дають можливість не тільки знаходити траєкторію руху частинки, а і показати її на поверхні і навіть зробити анімацію, яка по суті заміняє швидкісну зйомку. Такий підхід дає змогу досліджувати кінематичні параметри руху по різних гвинтових поверхнях без натурних зразків цих поверхонь, що значно здешевлює пошук потрібних поверхонь.

Розглянуто рух частинки по гвинтовому коноїду та розгортному гелікоїду. Встановлено, що для різних поверхонь характер руху частинки теж буде різний. При русі по поверхні гвинтового коноїда частинка за наявності тертя спочатку розганяється, а потім зупиняється на значній відстані від його осі. Щоб запобігти цьому, потрібно брати обмежений відсік коноїда як по висоті, так і по його периферії. При русі частинки по поверхні розгортного гелікоїда її швидкість з часом стає постійною, а траєкторією після цього буде гвинтова лінія.

При подальших дослідженнях необхідно за допомогою розроблених підходів виявити можливості сепарації матеріалу не тільки після стабілізації руху, а і під час перехідного процесу, оскільки стала можливою його візуалізація. Це дозволить підібрати відсік поверхні оптимального розміру, який забезпечить потрібну продуктивність сепарації за рахунок роззосередження частинок із різним коефіцієнтом тертя по його поверхні.

Ключові слова: ***математичне моделювання, траєкторія руху частинки, швидкість руху, гвинтовий коноїд, розгортний гелікоїд***