UDC 631.312 DOI 10.31548/energiya2022.01.082

FINDING THE TRAJECTORYOF MOVEMENT OF A MATERIAL PARTICLE ON THE INNER SURFACE OF A VERTICAL CYLINDER AT THE SIDE SUPPLY OF MATERIAL

S. Pylypaka, doctor of technical science

A. Nesvidomin, candidate of technical science

National University of Life and Environmental Sciences of Ukraine

E-mail: *a.nesvidomin@gmail.com*

Abstract. *The movement of material particles on the inner surface of the cylinder takes place in cyclones. Due to the complexity of the aerodynamics of the process, theoretical developments can not be used as a basis for calculating the design and efficiency of their operation. Because of this, a number of simplifications are allowed in the theoretical provisions, as a result of which the calculated data do not coincide with the experimental data.*

The use of modern software products, which have great graphics capabilities, allows you to get new results in solving such problems in the form of high-quality graphic illustrations.

The aim of the study is to determine the motion of a material particle that enters the inner surface of a vertical cylinder with a given initial velocity.

A number of simplifications were introduced in the calculations: air resistance, the effect of particles on each other, their size, etc. were not taken into account. Accompanying Frenet and Darboux triangles were used to find the trajectory.

Differential equations of motion of a material particle on the inner surface of a vertical cylinder are compiled. The equations are solved using the MatLab system.

It is established that the velocity of particles that fall on the inner surface of the cylinder decreases to a certain value, and then begins to increase. For specific conditions (coefficient of friction and radius of the cylinder), the value of the minimum speed to which the movement of particles is slowed down is approximately the same and does not depend on the value of the initial speed. This means that there is a minimum value of the initial velocity at which the particle will not slow down when it hits the surface of the cylinder. Since particles with different coefficients of friction at the initial stage of their movement on the cylinder are poorly scattered on its surface, for the effective operation of the cyclone you need to make an inlet window of sufficient size in the vertical direction.

In the absence of friction and air resistance, the particle moves so that its trajectory on the scan of the side surface of the cylinder is a parabola.

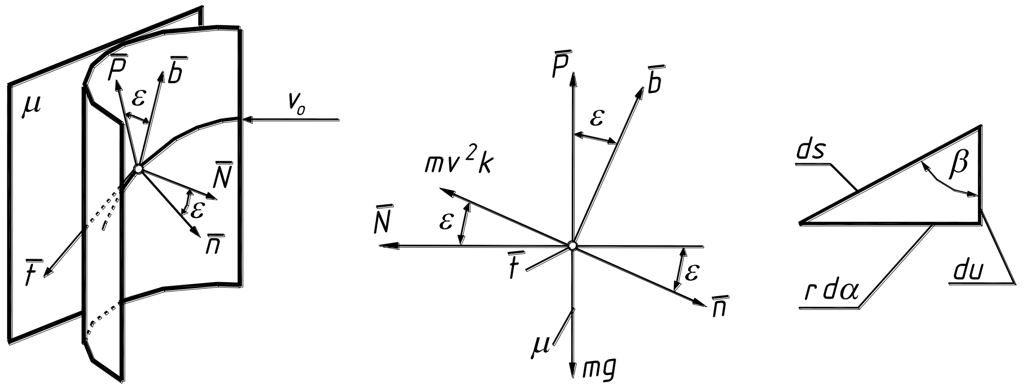
Key words: ***material particle, trajectory, cylinder, velocity***

Introduction. The movement of material particles on the inner surface of the cylinder occurs in cyclones, which are widely used to capture dust and prevent it from entering the atmosphere in industrial enterprises, including agriculture. Due to the complexity of the aerodynamics of the process, theoretical developments can not be used as a basis for calculating the design and efficiency of cyclones [1]. Because of this, a number of simplifications are allowed in the theoretical provisions, as a result of which the calculated data do not coincide with the data obtained in practice. But as Academician Vasylenko PM wrote "This does not reduce their practical value, because in many cases there is no need to obtain accurate values, and if necessary, these values can always be verified and refined on the basis of experimental data" [2]. At the same time, with the help of theoretical positions it is possible to detect the influence of some factors on the processes occurring in the cyclone.

Analysis of recent research and publications. The motion of a material particle with lateral feed on an inclined plane is considered in monographs [2, 3]. In these works, the motion of material particles on the inner surface of an inclined cylinder is also considered. The use of modern software products, which have great graphics capabilities, allows you to get new results in solving such problems in the form of high-quality graphic illustrations.

The aim of the article is to study the motion of a material particle that enters the inner surface of a vertical cylinder with a given initial velocity.

Materials and methods. If the material particle is directed with an initial velocity v_o to the inner wall of the cylinder perpendicular to its generator, then its further movement will include both rotation around the axis of the cylinder and lowering under the action of gravity. In further calculations, we will introduce a number of simplifications: we will not take into account the air resistance, because the particle is fed into the cylinder with it, the impact of particles on each other, their size, etc. To find the trajectory of motion, we take the material point as the vertex of the accompanying Frenet trihedron, which has three mutually perpendicular orts $\bar{t}\,\bar{n}\,\bar{b}$ (Fig. 1, *a*). The second accompanying Darboux triangle with orts $\bar{t}\bar{N}\bar{P}$ має has a common tangent to the trajectory with the Frenet trihedron. The orts $\bar{P}$, $\bar{b}$, $\bar{N}$, $\bar{n}$ lie in the plane normal to the trajectory and the orts $\bar{P}$ and $\bar{t}$ – in the plane μ tangent to the cylinder. Between the orts $\bar{P}$ and $\bar{b}$, $\bar{N}$ and $\bar{n}$ there is an angle ε (Fig. 1, *a*), which varies along the trajectory and is a function of its arc: $\varepsilon = \varepsilon(s)$.



a *b* *c*

Fig. 1. Graphic illustrations for the compilation of differential equations of motion of a material particle on the inner surface of a vertical cylinder:

a – the accompanying Frenet and Darboux triangles of the trajectory of the material particle; *b* – decomposition of acting forces in the normal plane of the trajectory; *c* – to determine the differential of the trajectory arc

Results and discussion. Consider the balance of forces in the projections on the orthographies of the Darbu trihedron. Let's project on ort $\bar{t}$ the forces giving to particles of acceleration $\frac{dv}{dt} = \frac{dv}{ds} \cdot \frac{ds}{dt} = v\frac{dv}{ds}$ (*t* – time, *s* – length of an arc of a trajectory):

$$mv\frac{dv}{ds} = mg\cos\psi - fR, \quad (1)$$

where *m* – is the mass of the particle; *f* – is the coefficient of friction; *R* – is the particle pressure on the cylinder surface; ψ – is the angle between the weight *mg* and orth $\bar{t}$; $g = 9{,}81\ m/s^2$. To determine the value of pressure *R*, consider the forces in the normal plane. To do this, we choose the point of view so that the orth $\bar{t}$ is projected into the point (Fig. 1, *b*).

The centrifugal force mv^2k ($k=k(s)$ – is the curvature of the trajectory) is directed along the orth $\bar{n}$ of the main normal in the opposite direction. Its component in the projection on the orth $\bar{N}$ will cause a certain amount of pressure. The weight of the particle *mg* does not affect the pressure, because its vector of action (down) is perpendicular to the vector normal $\overline{N}$ to the surface of the cylinder. Therefore, the force of pressure will be determined only by the component of the centrifugal force:

$$R = mv^2 k \cos\varepsilon. \tag{2}$$

Another component of the centrifugal force in the projection on the orth $\overline{P}$ acts in the tangent plane μ and balances the component of the force of gravity *mg*. Thus, the forces in the projection on the orth $\overline{P}$ will be written:

$$mv^2 k \sin\varepsilon = mg\cos\varphi, \tag{3}$$

where φ – is the angle between the force vector of gravity and the orth $\overline{P}$ of the Darboux trihedron. Substituting (2) into (1) and adding equation (3), we obtain a system of equations, which after reduction by mass *m* takes the form:

$$\begin{cases} v\dfrac{dv}{ds} = g\cos\psi - fv^2 k\cos\varepsilon; \\ v^2 k\sin\varepsilon = g\cos\varphi\ . \end{cases} \tag{4}$$

Since the trajectory lies on the surface of the cylinder, the expressions of angles ε, ψ, φ and curvature k must be expressed through one of its parameters. The parametric equations of the cylinder will be written:

$$X = r\cos\alpha; \qquad Y = r\sin\alpha; \qquad Z = u, \tag{5}$$

where α – is the angle of rotation of the surface point around the axis *OZ*; u – length of the rectilinear generatrix- variable parameters; r – is the radius of the cylinder.

The partial derivatives and the differential of the trajectory arc will be written:

$$\begin{gathered} X_\alpha = -r\sin\alpha; \qquad Y_\alpha = r\cos\alpha; \qquad Z_\alpha = 0; \\ X_u = 0; \qquad Y_u = 0; \qquad Z_u = 1; \\ ds^2 = du^2 + r^2 d\alpha^2. \end{gathered} \tag{6}$$

As can be seen from the expression of the arc differential (6), geometrically it can be represented as the hypotenuse of an elementary right triangle (Fig. 1, *c*). From fig. 1, in can be written:

$$du = r\cdot \mathrm{ctg}\,\beta\cdot d\alpha \qquad \text{where} \quad u = r\int \mathrm{ctg}\beta\cdot d\alpha\ , \tag{7}$$

where β – is the angle between the trajectory and the generating cylinder.

Having set a certain dependence $\beta = \beta(\alpha)$ we thus define a line on the cylinder. After substitution (7) in (5) the parametric equations of the line are written:

$$x = r\cos\alpha; \quad y = r\sin\alpha; \quad z = r\int \mathrm{ctg}\beta \cdot d\alpha \,. \tag{8}$$

Our task is to find a dependence $\beta = \beta(\alpha)$, in which line (8) would be a trajectory, ie satisfy system (4). To do this, we find the first and second derivatives of the parameter α equations (8), which are needed to determine the curvature k of the trajectory and angles ε, ψ, φ:

$$\begin{aligned} &x' = -r\sin\alpha; && y' = r\cos\alpha; && z' = r\mathrm{ctg}\beta; \\ &x'' = -r\cos\alpha; && y'' = -r\sin\alpha; && z'' = -\frac{r\beta'}{\sin^2\beta}. \end{aligned} \tag{9}$$

Substituting (9) into the known formula [4], we find the curvature of the trajectory:

$$k = \frac{\sin\beta}{r}\sqrt{\beta'^2 + \sin^2\beta}. \tag{10}$$

Derivatives (9) completely determine the direction of the main normal $\bar{n}$. The coordinates of its guide vector are also found by known formulas [4]:

$$\begin{aligned} n_x &= -\frac{r^3}{\sin^2\beta}\left(\beta' \cdot \mathrm{ctg}\beta \cdot \sin\alpha + \cos\alpha\right); \\ n_y &= \frac{r^3}{\sin^2\beta}\left(\beta' \cdot \mathrm{ctg}\beta \cdot \cos\alpha - \sin\alpha\right); \\ n_x &= -\frac{r^3\beta'}{\sin^2\beta}. \end{aligned} \tag{11}$$

The guiding vector of the orth $\bar{t}$ is the first derivatives (9). The direction of the vectors $\bar{N}$ and $\bar{P}$ is found as the vector product of two vectors: for $\bar{N}$ – the vector product of two vectors tangent to the coordinate lines of the cylinder (this is the first and second line (6)); for $\bar{P}$ – vector product of vector $\bar{t}$ and found vector $\bar{N}$. Omitting operations to find vectors, we write down the finished results:

$$\begin{aligned} &N_x = -r\cos\alpha; && N_y = -r\sin\alpha; && N_z = 0; \\ &P_x = -r^2\mathrm{ctg}\beta \cdot \sin\alpha; && P_y = r^2\mathrm{ctg}\beta \cdot \cos\alpha; && P_z = -r^2. \end{aligned} \tag{12}$$

Knowing the coordinates of the vectors, we find the expressions for the desired angles between them (the coordinates of the vector of gravity will be *{0, 0, 1}*, and we assume that the *OZ* axis is directed downward):

$$\cos\varepsilon = \frac{\sin\beta}{\sqrt{\beta'^2 + \sin^2\beta}} \qquad \sin\varepsilon = \frac{\beta'}{\sqrt{\beta'^2 + \sin^2\beta}};$$

$$\cos\varphi = -\sin\beta; \quad \text{where} \quad \psi = \beta. \tag{13}$$

We found all expressions for the angles and curvatures of the trajectory included in system (4), due to the dependence $\beta = \beta(\alpha)$. We do the same for the differential of the arc *ds*, which is included in the first equation of system (4). Substituting *du* from (7) into the expression of the arc differential (6), we obtain:

$$ds = \frac{r \cdot d\alpha}{\sin\beta}. \tag{14}$$

Substitute the expression of the differential of the arc from (14), the expressions of the angles from (13) and the curvature from (10) into the system (4). After simplifications, we obtain a system of two differential equations, which includes two unknown functions: $\beta = \beta(\alpha)$ and $v = v(\alpha)$:

$$\begin{cases} v\dfrac{dv}{d\alpha} = rg\,\mathrm{ctg}\beta - fv^2\sin\beta; \\ v^2\beta' = -rg. \end{cases} \tag{15}$$

From the second equation of system (15) we have:

$$v^2 = -\frac{rg}{\beta'}$$

After differentiation

$$v\frac{dv}{d\alpha} = \frac{rg\beta''}{2\beta'^2}. \tag{16}$$

Substituting both expressions from (16) into the first equation of system (15), we obtain a differential equation with one unknown function: $\beta = \beta(\alpha)$:

$$\beta'' = 2\beta'\left(f\sin\beta + \beta'\mathrm{ctg}\beta\right). \tag{17}$$

As can be seen from (17), the dependence $\beta = \beta(\alpha)$ does not depend on the radius *r*. The integration of equation (17) and the construction of trajectories according to equations

(8) was carried out using the *SimuLink* package in the *MatLab* environment. The initial value of β' during integration was determined from the first expression (16) depending on the value of the initial velocity v_o by the formula $\beta' = -rg/v_0^2$, and the initial value of β was taken as 90^0 (Fig. 2, *a*) according to the condition of the problem and $\beta = 135^0$ (Fig. 2, *b*). In Fig. 3 plots of changes in the velocity of a material particle depending on the angle of rotation α (Fig. 3, *a*) and the time of movement *t* (Fig. 3, *b*). The motion time *t* was found by numerical integration of the expression, which was obtained as follows. Rewriting the expression for the velocity v as well as $v = \frac{ds}{dt} = \frac{ds}{d\alpha}\ \frac{d\alpha}{dt}$ substituting in it the derivative $s' = r/\sin\beta$ from (14), we obtained:

$$v = \frac{r}{\sin\beta}\frac{d\alpha}{dt}, \tag{18}$$

where $t = r\int\frac{d\alpha}{v\sin\beta}$.

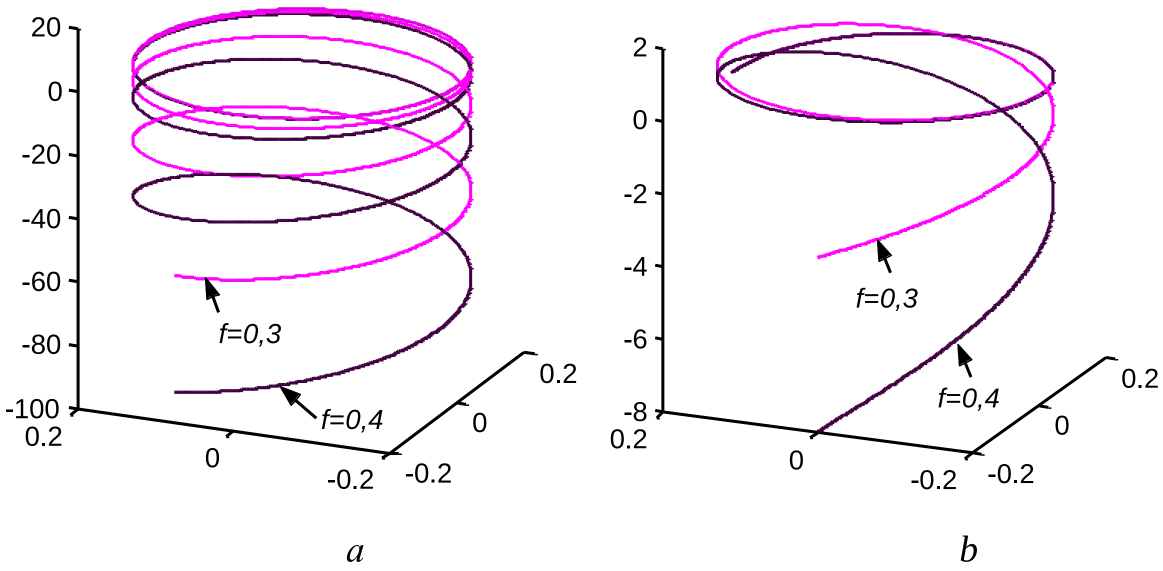


Fig. 2. The trajectories of particles with the specified coefficient of friction, which enter the inner surface of the cylinder radius *r=0,2 m* with an initial velocity v_o=10 m/s:

a – at an angle $\beta = 90^0$; *b* - at an angle $\beta = 135^0$

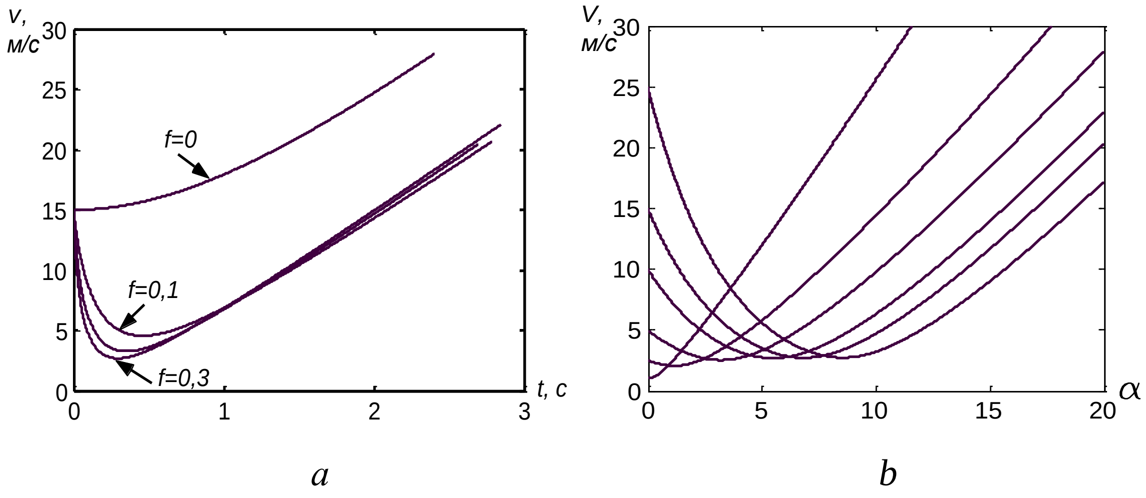


Fig. 3. Graphs of changes in velocities of material particles on the inner surface of a vertical cylinder of radius *r=0,2 m*:

a - at equal initial velocities $v_o=15$ *m/s* and different coefficients of friction f (*0; 0,1; 0,2* and *0,3*);

b - with the same coefficient of friction $f=0,3$ and different initial velocities v_o (*1; 2,5; 5; 10; 15* and *25 m/s*)

Having two dependences $v=v(\alpha)$ and $t=t(\alpha)$, obtained by numerical integration, *MatLab* allows to exclude the common parameter α and to obtain the dependence of velocity on time $v=v(t)$. In Fig. 3, and graphs of changes in velocities of material particles with different coefficients of friction are shown. From Fig. 3, and it is seen that the coefficient of friction has little effect on the velocity of movement (except in the case of $f = 0$): after a second the velocities of all particles are equalized and grow equally over time. This indicates a small scattering of particles on the surface, which come to the wall of the cylinder in the same place (this can be seen from the trajectories in Fig. 2, especially at the beginning of the movement). From the graphs (Fig. 3, *a*) it is seen that the velocity of the particles is quenched to a certain value, and then begins to increase again. In fig. 3, *b* plots of changes in velocity depending on the angle of rotation α for different initial values of velocity v_o. From Fig. 3 it would be seen that the limit to which the velocity falls is approximately the same for particles with different initial velocities and is approximately equal to *2,5 m/s* (for $r=0,2$ *m* and $f=0,3$). The drop in speed occurs within the first two turns.

It should be noted that the dependence of the particle velocity on the angle β(v=$v(\beta)$) can be obtained analytically by integrating equation (17). Since there is no independent variable α, it is a substitution

$$\beta' = p; \qquad \beta'' = p\frac{dp}{d\beta} \tag{19}$$

equation (17) is reduced to a first-order differential equation:

$$p\frac{dp}{d\beta} = 2p\left(f \sin\beta + p \quad \text{ctg}\beta\right). \tag{20}$$

Reducing equation (20) by p, we obtain a linear differential equation, which after integration takes the form:

$$p = 2f\sin^2\beta \quad \ln \quad \text{tg}\frac{\beta}{2} \quad + c \quad \sin^2\beta, \tag{21}$$

where c – is the constant integration. Based on the condition that at $\beta = 90^0$ $\beta' = p = -rg/v_0^2$, we find the value of the integration constant $c = -rg/v_0^2$, after which expression (21) is written:

$$p = \sin^2\beta \quad 2f \quad \ln \quad \text{tg}\frac{\beta}{2} \qquad \frac{rg}{v_0^2} \quad . \tag{22}$$

According to the first equation (16) we finally write:

$$v = \frac{v_0}{\sin\beta}\sqrt{\frac{rg}{rg \quad 2f \quad v_0^2 \quad \ln\left(\text{tg}\,\beta/2\right)}}. \tag{23}$$

According to the obtained expression (23) it is possible to construct graphs of dependence v=$v(\beta)$, but they do not reflect the physical essence of the process as much as graphs of dependence on time t (Fig. 3, a) or angle of rotation α (Fig. 3, b), since the angle β also depends on these “more independent” parameters.

When we try to further integrate, we come to the dependence $d\beta = p \quad d\alpha$ according to the first expression (19), where we can write:

$$d\alpha = \frac{d\beta}{p} \qquad \frac{v_0^2 d\beta}{v_0^2 \quad \ln\left(\text{tg}\,\beta/2\right) \quad rg]}. \tag{24}$$

Substituting the expressions $d\alpha$ from (24) and *v=v(β)* from (23) the second expression (18), we obtain the integral for finding the time of motion of the particle:

$$t = -v_0\sqrt{\frac{r}{g}}\int\frac{d\beta}{\sin^2\beta\sqrt{rg - 2f\cdot v_0^2\cdot\ln\left(\mathrm{tg}\,\beta/2\right)}}. \tag{25}$$

Unfortunately, expressions (24), (25) cannot be integrated and written through elementary functions (their integration leads to special functions). However, for *f =0* ((for a perfectly smooth cylinder surface), the integration of these expressions gives simple dependencies. We write them after integration, as well as expression (23) for *f=0*:

$$\alpha = \frac{v_0^2}{rg}\mathrm{ctg}\beta; \qquad t = \frac{v_0}{g}\mathrm{ctg}\beta; \qquad v = \frac{v_0}{\sin\beta}. \tag{26}$$

In order to find the equation of the trajectory, it is necessary to integrate expression (7). To do this, we substitute the expression $d\alpha$ from (24) for *f =0* and after integration we obtain:

$$u = \frac{v_0^2}{2g\sin^2\beta} + c \qquad \text{or} \qquad u = \frac{v_0^2}{2g}\mathrm{ctg}^2\beta. \tag{27}$$

The second expression (27) is obtained by finding the integration constant *c* provided that *z=u=0* at $\beta = 90^0$. Excluding the angle β in (26), (27), we obtain new dependences as a function of time:

$$\alpha = \frac{v_0}{r}t; \qquad u = \frac{g}{2}t^2. \tag{28}$$

Substituting expressions (28) in (5), we obtain the parametric equations of the trajectory of the material particle on the inner surface of a perfectly smooth cylinder:

$$x = r\cos\left(\frac{v_0}{r}t\right); \qquad y = r\sin\left(\frac{v_0}{r}t\right); \qquad z = \frac{g}{2}t^2. \tag{29}$$

To get a better idea of the trajectory, we find it on the scan of the cylinder. Given that the side surface of the cylinder turns into a rectangle on the scan, we combine the x_p axis with its base, and the z_p – axis - along the generative and we obtain the equation of the trajectory on the scan:

$$x_p = r\alpha = v_0 t; \qquad z_p = \frac{g}{2}t^2, \qquad \text{from} \qquad z_p = \frac{g}{2v_0^2}x_p^2. \tag{30}$$

Therefore, the trajectory of the particle in the sweep of the cylinder is a parabola, ie the particle in the absence of friction and air resistance moves like a body thrown at an angle to the horizon. The cylinder imposes restrictions on the movement of the particle, forcing it to move on its surface.

Conclusions and prospects for further research. The velocity of the particles entering the inner surface of the cylinder decreases to a certain value and then begins to increase. For specific conditions (coefficient of friction and radius of the cylinder), the value of the minimum speed to which the movement of particles is slowed down is approximately the same and does not depend on the value of the initial velocity. This means that there is a minimum value of the initial velocity at which the particle when entering the surface of the cylinder will not slow down its movement. Since particles with different coefficients of friction at the initial stage of their movement on the cylinder are poorly scattered on its surface, for the effective operation of the cyclone you need to make an inlet window of sufficient size in the vertical direction.

In the absence of friction and air resistance, the particle moves so that its trajectory on the scan of the side surface of the cylinder is a parabola, ie like a body thrown at an angle to the horizon.

List or references

1. Гордон Г. М., Пейсахов И. Л. Пылеулавливание и очистка газов в цветной металлургии. Л.-М.: Металлургия, 1977. 456 с.

2. Василенко П. М. Теория движения частицы по шероховатым поверхностям сельскохозяйственных машин. К.: УАСХН, 1960. 283 с.

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

4. Милинский В. И. Дифференциальная геометрия. Л., 1934. 332 с.

References

1. Gordon, G. M., Peysakhov, I. L. (1977). Pyleulavlivaniye i ochistka gazov v tsvetnoy metallurgii [Dust collection and gas cleaning in non-ferrous metallurgy]. Leningrad-Moskow: Metallurgiya, 456.

2. Vasilenko, P. M. (1960). Teoriya dvizheniya chastitsy po sherokhovatym poverkhnostyam sel′skokhozyaystvennykh mashin [Theory of particle motion on rough surfaces of agricultural machines]. Kyiv: UASKHN, 283.

3. Zaika, P. M. (1992). Izbrannyye zadachi zemledel′cheskoy mekhaniki [Selected tasks of agricultural mechanics]. Kyiv: Izd-vo USKHA, 507.

4. Milinskiy, V. I. (1934). Differentsial′naya geometriya [Differential geometry]. Leningrad, 332.

ЗНАХОДЖЕННЯ ТРАЄКТОРІЙ РУХУ МАТЕРІАЛЬНОЇ ЧАСТИНКИ ПО ВНУТРІШНІЙ ПОВЕРХНІ ВЕРТИКАЛЬНОГО ЦИЛІНДРА ПРИ БОКОВІЙ ПОДАЧІ МАТЕРІАЛУ

С. Ф. Пилипака, А. В. Несвідомін

Анотація. *Рух матеріальних частинок по внутрішній поверхні циліндра має місце в циклонах. Із-за складності аеродинаміки процесу теоретичні розробки не можуть бути покладені в основу розрахунку конструкції і ефективності їх експлуатації. Через це в теоретичних положеннях допускається ряд спрощень, в результаті яких розрахункові дані не співпадають з еспериментальними даними.*

Застосування сучасних програмних продуктів, в які закладені великі графічні можливості, дозволяє одержати нові результати при розв'язуванні подібних задач у вигляді графічних ілюстрацій високої якості.

Метою дослідження є визначення руху матеріальної частинки, яка вступає на внутрішню поверхню вертикального циліндра із заданою початковою швидкістю.

При розрахунках було введено ряд спрощень: не враховували опір повітря, вплив частинок одна на одну, їх розміру тощо. Для знаходження траєкторії руху прийняті супровідні тригранники Френе та Дарбу.

Складено диференціальні рівняння руху матеріальної частинки по внутрішній поверхні вертикального циліндра. Рівняння розв'язані за допомогою системи MatLab.

Встановлено, що швидкість частинок, які потрапляють на внутрішню поверхню циліндра, зменшується до певної величини, а потім починає зростати. Для конкретних умов (коефіцієнта тертя та радіуса циліндра) значення мінімальної швидкості, до якої сповільнюється рух частинок, приблизно однаковий і не залежить від величини початкової швидкості. Це означає, що існує мінімальне значення початкової швидкості, при якій частинка при потраплянні на поверхню циліндра не буде гальмувати свій рух. Оскільки частинки з різними коефіцієнтами тертя на початковому етапі свого руху по циліндру слабко розсіваються по його поверхні, то для ефективної роботи циклона потрібно робити впускне вікно достатньої величини у вертикальному напрямі.

У випадку відсутності тертя і опору повітря частинка рухається так, що її траєкторією на розгортці бічної поверхні циліндра є парабола.

Ключові слова: *матеріальна частинка, траєкторія руху, циліндр, швидкість руху*

НАХОЖДЕНИЕ ТРАЕКТОРИЙ ДВИЖЕНИЯ МАТЕРИАЛЬНОЙ ЧАСТИЦЫ ПО ВНУТРЕННЕЙ ПОВЕРХНОСТИ ВЕРТИКАЛЬНОГО ЦИЛИНДРА ПРИ БОКОВОЙ ПОДАЧЕ МАТЕРИАЛА

С. Ф. Пилипака, А. В. Несвидомин

Аннотация. *Движение материальных частиц по внутренней поверхности цилиндра происходит в циклонах. Из-за сложности аэродинамики процесса теоретические разработки не могут быть положены в основу расчета* *конструкции и эффективности их эксплуатации. Поэтому в теоретических положениях допускается ряд упрощений, в результате которых расчетные данные не совпадают с эспериментальными данными.*

Применение современных программных продуктов, в которые заложены большие графические возможности, позволяет получить новые результаты при решении подобных задач посредством графических иллюстраций высокого качества.

Целью исследования является определение движения материальной частицы, поступающей на внутреннюю поверхность вертикального цилиндра с заданной начальной скоростью.

При расчетах был введен ряд упрощений: не учитывалось сопротивление воздуха, влияние частиц друг на друга, их размера и т.д. Для нахождения траектории движения приняты сопроводительные трехгранники Френе и Дарбу.

Составлены дифференциальные уравнения движения материальной частицы по внутренней поверхности вертикального цилиндра. Уравнения решены с помощью системы MatLab.

Установлено, что скорость попадающих на внутреннюю поверхность цилиндра частиц снижается до определенной величины, а затем начинает расти. Для конкретных условий (коэффициента трения и радиуса цилиндра) значение минимальной скорости, к которой происходит замедление движение частиц, примерно одинаково и не зависит от величины начальной скорости. Это означает, что существует минимальное значение исходной скорости, при которой частица при попадании на поверхность цилиндра не будет тормозить свое движение. Поскольку частицы с разными коэффициентами трения на начальном этапе своего движения по цилиндру слабо рассеиваются по его поверхности, то для эффективной работы циклона нужно создать впускное окно достаточной величины в вертикальном направлении.

В случае отсутствия трения и сопротивления воздуха частица движется так, что ее траекторией на развертке боковой поверхности цилиндра является парабола.

Ключевые слова: ***материальная частица, траектория движения, цилиндр, скорость движения***