Kinematic analysis of a slider mechanism using the graph-analytical method of velocity diagrams

Sharipov Shuhrat Po‘latovich
Associate Professor, Karshi State Technical University.

Saidova Gulasal Botirxon qizi
Teacher, Kasbi Industrial and Service College.

Abstract. This article studies the kinematic analysis of a slider mechanism based on the graph-analytical method. Velocity diagrams were constructed for the main links of the mechanism, and the linear velocities of points as well as the relative motion parameters of the links were determined. During the research, the geometric and kinematic relationships of the crank-slider mechanism were analyzed, and the stages of constructing the velocity diagram were consistently described. Using the graph-analytical method, the possibility of determining the velocity parameters of the mechanism in different positions was demonstrated. The research results can be effectively applied in the teaching of mechanism theory, engineering graphics, and technical sciences.

Keywords: slider mechanism, crank-slider mechanism, kinematic analysis, velocity diagram, graph-analytical method, mechanism kinematics, velocity vector, relative velocity, engineering graphics, theory of mechanisms.

Аннотация. В данной статье рассматривается кинематический анализ ползунного механизма методом графоаналитического построения плана скоростей. Раскрыта методика определения скоростей звеньев механизма, направления движения ползуна, а также взаимосвязи между угловыми и линейными скоростями. Особое внимание уделено практическому применению графоаналитического метода при изучении механизмов в инженерной подготовке студентов. Представленный подход способствует развитию пространственного мышления, расчетно-графических навыков и более глубокому пониманию кинематических процессов в механизмах.

Ключевые слова: ползунный механизм, кинематический анализ, план скоростей, графоаналитический метод, звено, ползун, угловая скорость, линейная скорость, инженерная графика, механизм.

INTRODUCTION.

In the process of designing machinery, automation systems, transport equipment, and technological devices, determining the kinematic and dynamic characteristics of various mechanisms is of great scientific and practical importance. In particular, slider mechanisms that convert rotary motion into reciprocating translational motion are widely used in internal combustion engines, compressors, pumps, press equipment, and many other mechanical systems. Therefore, determining and analyzing the motion parameters of such mechanisms is considered one of the main tasks of the theory of mechanisms [1, p.18].

The kinematic analysis of mechanisms serves to determine the motion, velocity, and acceleration of their links. Determining kinematic parameters plays an important role in increasing the productivity, reliability, and energy efficiency of a mechanism. In particular, determining the velocities of the links of a slider mechanism makes it possible to select the optimal operating mode of the mechanism and reduce vibrations and excessive dynamic loads [2, p.41].

Currently, analytical, graphical, graph-analytical, and computer simulation methods are used in the analysis of mechanisms. Although analytical methods provide high accuracy, they require complex mathematical calculations. Graphical methods are convenient due to their geometric visualization capabilities; however, in some cases, their level of accuracy may be lower. The graph-analytical method combines the advantages of both approaches and makes it possible to determine the kinematic parameters of mechanisms in a simple and understandable way [3,p.56].

Constructing the velocity diagram of a slider mechanism is based on the graphical representation of the relative motions between the links of the mechanism. With the help of the velocity diagram, it is possible to determine the magnitude and direction of the linear velocities at any point of the mechanism. This also has significant didactic importance in teaching the theory of mechanisms, as it develops students' spatial imagination, graphical thinking, and skills for analyzing mechanical processes [4, p.73].

In the process of constructing a velocity diagram using the graph-analytical method, the geometric scheme of the mechanism, scale coefficients, and the interrelations of velocity vectors are taken into account. This method makes it possible to represent the motion laws of the mechanism links in graphical form and significantly simplifies complex calculations [5, p.64].

In technical higher educational institutions, special attention is paid to the kinematic analysis of slider mechanisms in the teaching of subjects such as "Theory of Mechanisms and Machines," "Engineering Graphics," and "Theoretical Mechanics." This is because such mechanisms are used as one of the main transmission mechanisms in many technological systems of industry. Therefore, improving the methodology for determining their velocity parameters using the graph-analytical method is considered one of the urgent scientific and practical issues [6, p.29].

The purpose of this research is to construct the velocity diagram of a slider mechanism using the graph-analytical method, determine the velocity parameters of the mechanism links, and develop an effective algorithm for kinematic analysis. During the study, the geometric and kinematic relationships of the mechanism are analyzed, and the motion laws of the links are determined based on the graphical construction of velocity vectors.

Literature Review.

In the theory of mechanisms and machines, the kinematic analysis of slider mechanisms has long been considered one of the important areas of scientific research. Issues related to determining the motion parameters of mechanisms, calculating their velocities and accelerations, and optimizing their operating processes have been studied by many researchers [7, p.34].

In the early scientific studies devoted to mechanism kinematics, the main focus was placed on analytical calculation methods, where the motion equations of mechanism links were determined based on differential and trigonometric relationships. In particular, Ivan Artobolevsky developed the fundamental principles of the theory of mechanisms and presented the theoretical foundations for determining the motion parameters of crank-slider mechanisms [8, p.52].

In subsequent studies, the effectiveness of using graphical and graph-analytical methods in the kinematic analysis of mechanisms was substantiated. These methods made it possible to reduce complex mathematical calculations and accurately represent the geometric relationships between the mechanism links [9, p.61].

The graph-analytical method is recognized as one of the most convenient and illustrative methods in the theory of mechanisms. In this method, velocities and accelerations are constructed graphically through special diagrams. As a result, the motion parameters at any point of the mechanism can be determined by means of geometric constructions [10, p.47].

Scientific sources recommend the use of the vector method, scale coefficients, and the law of relative velocities in constructing the velocity diagram of a slider mechanism. In particular, constructing the velocity polygon makes it possible to graphically represent the relationships between the mechanism links with high accuracy [11, p.58].

In recent years, computer technologies have been widely applied in the kinematic analysis of mechanisms. With the help of CAD and CAE software, it is possible to model the motion of mechanisms and automatically generate velocity and acceleration diagrams. However, the graph-analytical method still remains relevant in technical higher education institutions due to its simplicity, visual clarity, and effectiveness in the educational process [12, p.75].

Research related to teaching engineering graphics and the theory of mechanisms has noted that the graph-analytical approach is an important tool for developing students' spatial thinking. During the process of graphical construction, students gain a deeper understanding of the geometric nature of mechanical motions and better comprehend the functional relationships between mechanism elements [13, p.39].

The analyzed scientific sources show that constructing the velocity diagram of a slider mechanism using the graph-analytical method is one of the important practical directions in the theory of mechanisms. However, existing studies do not sufficiently address issues related to simplifying the algorithms for constructing velocity diagrams, improving graphical accuracy, and adapting them to the educational process. Therefore, the present study aims to develop an effective graph-analytical algorithm for constructing the velocity diagram of a slider mechanism and to analyze its kinematic capabilities.

Research Methodology.

In this study, the kinematic parameters of a crank-slider mechanism were analyzed using the graph-analytical method. A classical slider mechanism that converts rotary motion into reciprocating translational motion was selected as the object of the study. The mechanism consists of a driving crank, a connecting rod, and a slider, whose mutual motions were investigated based on kinematic relationships [14, p.42].

The kinematic scheme of the slider mechanism is considered a planar mechanism widely used in the theory of mechanisms and machines. During the research, the mechanism links were assumed to be absolutely rigid bodies, and friction forces in the kinematic pairs were neglected. The angular velocity of the crank, acting as the driving link, was assumed to be constant [16,p.53].

As a result of the crank rotation, the connecting rod performs complex planar motion, while the slider carries out reciprocating translational motion along the guide. In order to determine the velocity parameters of each mechanism link, the graph-analytical analysis method was applied. This method is based on the graphical construction of velocity vectors for the mechanism points [16, p.53].

In the kinematic analysis, the geometric scheme of the mechanism was first constructed for a given position. Then, based on a selected scale, the velocity diagram was created. While constructing the velocity diagram, the following main properties of velocity vectors were used: the velocity of a point on a rotating link is directed perpendicular to the radius; the velocity of the slider is directed along its line of motion; and the relative velocity vector is perpendicular to the connecting link [16, p.53].

The relative motion method was used in constructing the velocity diagram of the slider mechanism. In this method, the velocity of one point relative to another was determined according to the geometric addition law. During the construction of the velocity vectors, a velocity polygon was formed, and the unknown velocities of the mechanism links were determined graphically [16, p.53].

During the study, the scale coefficient of the velocity diagram was determined using the following relationship:

$$\mu_v = \frac{v}{l_v}$$

where: μ_v — scale coefficient of the velocity diagram;
v — actual velocity value; lv — length of the velocity vector in the diagram.

The linear velocity of the point at the end of the crank was calculated using the following formula:

$$v_A = \omega_1 \cdot OA$$

where:

ω_1 — angular velocity of the crank; OA — length of the crank.

The relative velocities of the points on the connecting rod were determined based on the following equation:

$$\vec{v}_B = \vec{v}_A + \vec{v}_{BA}$$

Using this methodology, it became possible to construct the velocity diagram for any position of the mechanism, determine the velocities of the links, and analyze the kinematic relationships graphically. The advantages of the graph-analytical method include the simplicity of calculations, visual clarity, and convenience in engineering practice [17, p.18].

Construction of the kinematic scheme and velocity diagram of the slider mechanism

The crank-slider mechanism belongs to the class of planar mechanisms and serves to convert rotary motion into reciprocating translational motion. The main elements of the mechanism consist of a fixed support, a crank, a connecting rod, and a slider. The crank acts as the driving link and performs rotational motion with a constant angular velocity, as a result of which reciprocating motion is transmitted to the slider through the connecting rod [17, p.18].

In the kinematic scheme of the mechanism:

- point O is taken as the fixed center of rotation;
- OA is the crank;
- AB is the connecting rod;
- point B is the center of the slider.

During the rotation of the crank, point A moves along a circular path. The linear velocity of this point is directed perpendicular to the radius and is determined by the following relationship:

$$v_A = \omega_1 \cdot r$$

where:

v_A — linear velocity of point A;

ω_1 — angular velocity of the crank;

r— crank radius.

The connecting rod performs complex planar motion. Therefore, the velocity of point B consists of the sum of the velocity of point A and the relative velocity of point B with respect to point A [17, p.18]:

$$\vec{v}_B = \vec{v}_A + \vec{v}_{BA}$$

The construction of the velocity diagram is carried out in the following sequence:

Stage 1. Constructing the Given Position of the Mechanism

First, the geometric scheme of the crank-slider mechanism is drawn according to a specified scale. The crank rotation angle and the dimensions of the links are determined.

Stage 2. Determining the Velocity of the Driving Point

The velocity vector of point A is constructed in a direction perpendicular to the crank. The vector length is determined according to the selected scale.

The scale of the velocity diagram is determined as follows:

$$\mu_v = \frac{v_A}{P_a}$$

where:

μv — velocity scale;

P_a — vector length in the velocity diagram.

Stage 3. Constructing the Relative Velocity Vector

The relative velocity of point B with respect to point A is constructed perpendicular to the connecting rod (AB). This is because, in the relative rotation of a rigid body, the relative velocity of a point is perpendicular to the link [18,p.149].

Stage 4. Determining the Slider Velocity

Since the slider moves only along the guide, the velocity vector of point BBB is directed along the guide axis. The actual velocity of the slider is determined through the graphical intersection point.

Stage 5. Completing the Velocity Diagram

Using the obtained velocity polygon, the following parameters are determined:

- linear velocities of the links;
- relative velocities;
- directions of motion.

The velocity diagram constructed using the graph-analytical method makes it possible to represent the kinematic state of the mechanism visually. This method clearly illustrates the functional relationships between the mechanism links and significantly simplifies complex mathematical calculations [18, p.149].

Graph-analytical calculations and kinematic analysis

To determine the kinematic parameters of the slider mechanism, a velocity diagram was constructed based on the given geometric and kinematic dimensions of the mechanism. During the study, the following initial parameters were adopted:

- crank length — OA=0.1m;
- connecting rod length — AB=0.4 m;
- angular velocity of the crank — ω1=20 rad/s;
- crank rotation angle — φ=45◦ .

First, the linear velocity of point A at the end of the driving crank was determined. Since point A moves along a circular path, its velocity is directed perpendicular to the radius [18, p.149].

The velocity of point A was calculated using the following formula:

$$v_A = \omega_1 \cdot OA$$

Substituting the given values into the formula:

$$v_A = 20 \times 0.1 = 2\,m/s$$

Thus, the linear velocity of point A is equal to $v_A = 2\,m/s$.

To construct the velocity diagram, a scale coefficient was selected. In the graphical construction, 1cm was taken to correspond to 0.5m/s. Accordingly, the velocity scale was determined as:

$$\mu_v = \frac{v}{l_v}$$

The length of the velocity vector of point AAA was constructed as:

$$P_a = \frac{2}{0.5} = 4\,sm$$

In the next stage, the relative velocity vector of the connecting rod was determined. As is known, in the relative rotation of a rigid body, the relative velocity of a point is directed perpendicular to the link. Therefore, the vector v_{BA} was drawn perpendicular to the connecting rod AB [19, p.83].

The absolute velocity of point B was determined using the following vector equation:

$$\vec{v}_B = \vec{v}_A + \vec{v}_{BA}$$

Since the slider moves only along the guide, the velocity vector of point B was assumed to be horizontal. Using the graphical intersection method, the velocity polygon was constructed and the velocity of point B was determined.

According to the graphical measurement results:

$$P_b = 3.2\,sm$$

Based on the selected scale, the actual velocity of the slider became:

$$v_B = 3.2 \times 0.5 = 1.6\,m/s$$

To determine the angular velocity of the connecting rod, the relative velocity formula was used:

$$v_{BA} = \omega_{AB} \cdot AB$$

Based on the graphical construction:

$$v_{BA} = 1.2\,m/s$$

then the angular velocity of the connecting rod is:

$$\omega_{AB} = \frac{1.2}{0.4} = 3\,rad/s$$

The obtained results showed that the graph-analytical method makes it possible to determine the velocity parameters of the slider mechanism with sufficient accuracy. This method clearly represents the kinematic relationships between the mechanism links in graphical form and significantly simplifies complex mathematical calculations.

Results and Discussion

During the research, the kinematic parameters of the crank-slider mechanism were analyzed using the graph-analytical method, and the velocity diagram was constructed. The obtained results made it possible to clearly represent the kinematic relationships between the mechanism links. Using the constructed velocity diagram, the linear velocities, relative velocities, and angular velocities of the mechanism links were determined and their interdependence was analyzed.

According to the calculation results, the linear velocity of point A at the end of the crank was determined as:

$$v_A = 2\,m/s$$

The velocity vector of this point is directed perpendicular to the crank radius, and it was observed that the value of the velocity remains constant when the driving link of the mechanism rotates with constant angular velocity.

The velocity of point BBB, which is considered the center of the slider, was determined as:

$$v_B = 1.6\,m/s$$

The research results showed that the velocity of the slider changes depending on the crank rotation angle. During the crank rotation, the slider velocity increases and decreases non-uniformly. This phenomenon is one of the main kinematic characteristics of slider mechanisms.

The angular velocity generated as a result of the relative rotation of the connecting rod was obtained as:

$$\omega_{AB} = 3\,rad/s$$

This result confirms that the connecting rod performs complex planar motion. Since the connecting rod simultaneously participates in both translational and rotational motion, its points possess different velocity values.

The following advantages of the velocity diagram constructed using the graph-analytical method were identified:

- the ability to clearly show the directions of velocities of mechanism points graphically;
- reduction of complex mathematical calculations;
- visual representation of kinematic relationships;

- high didactic effectiveness in teaching the theory of mechanisms.

The analysis showed that the graph-analytical method is especially effective in teaching subjects such as “Theory of Mechanisms and Machines,” “Theoretical Mechanics,” and “Engineering Graphics” in technical higher educational institutions. During the graphical construction process, students gain a deeper understanding of the functional relationships between mechanism links, while their spatial imagination and graphical thinking are developed.

In addition, the research results demonstrated the possibility of integrating the graph-analytical method with modern computer technologies. Using CAD systems, it becomes possible to automatically construct velocity diagrams and analyze mechanism parameters with high accuracy.

Overall, the obtained results confirmed that the graph-analytical analysis of the velocity diagram of a slider mechanism is an effective and practically convenient method for determining the kinematic characteristics of mechanisms.

Conclusion

In this research, the velocity diagram of a slider mechanism was kinematically analyzed using the graph-analytical method. During the study, the geometric and kinematic relationships of the mechanism were investigated, and an effective algorithm for determining the velocity parameters of the links was developed.

Using the graph-analytical method, velocity vectors for the main points of the mechanism were constructed, making it possible to determine graphically the motion parameters of the crank, connecting rod, and slider. According to the research results, the following were determined and analyzed:

- the linear velocity of the point at the end of the crank;
- the translational velocity of the slider;
- the relative angular velocity of the connecting rod;

as well as the kinematic relationships between them.

The obtained results demonstrated the following advantages of the graph-analytical method:

- the possibility of visually determining mechanism motion parameters;
- simplification of complex mathematical calculations;
- graphical representation of functional relationships between mechanism links;
- high didactic effectiveness in teaching technical disciplines.

During the research, it was substantiated that the algorithm for constructing the velocity diagram is an effective tool for solving practical problems in the theory of mechanisms. It was established that this method makes it possible to determine the velocity parameters of the mechanism for any position with sufficient accuracy.

It was also noted that integrating the graph-analytical method with modern CAD technologies enables automated kinematic analysis of mechanisms. This contributes to the wider implementation of innovative approaches in teaching the subjects of mechanism theory and engineering graphics.

The results of this research can be applied in technical higher educational institutions in teaching subjects such as “Theory of Mechanisms and Machines,” “Theoretical Mechanics,” and “Engineering Graphics,” as well as in the design and analysis of mechanical systems.

References:

1. Артоболевский И.И. Теория механизмов и машин. – Москва: Наука, 1988. – 640 с.
2. Добровольский В.В. Теория механизмов и машин. – Ташкент: Ўқитувчи, 1991. – 432 б.
3. Кожевников С.Н. Теория механизмов и машин. – Москва: Машиностроение, 1976. – 592 с.
4. Norton R.L. Design of Machinery: An Introduction to the Synthesis and Analysis of Mechanisms and Machines. – New York: McGraw-Hill, 2012. – 857 p.
5. Shigley J.E., Uicker J.J. Theory of Machines and Mechanisms. – Oxford University Press, 2011. – 734 p.

6. Mabie H.H., Reinholtz C.F. Mechanisms and Dynamics of Machinery. – New York: Wiley, 1987. – 512 p.
7. Uicker J.J., Pennock G.R., Shigley J.E. Theory of Machines and Mechanisms. – Oxford University Press, 2017. – 768 p.
8. Litvin F.L. Theory of Gearing. – New York: NASA Reference Publication, 1989. – 470 p.
9. Erdman A.G., Sandor G.N. Mechanism Design: Analysis and Synthesis. – New Jersey: Prentice Hall, 1997. – 756 p.
10. Wilson C.E., Sadler J.P. Kinematics and Dynamics of Machinery. – New York: Harper Collins Publishers, 1993. – 650 p.
11. Hunt K.H. Kinematic Geometry of Mechanisms. – Oxford: Clarendon Press, 1978. – 540 p.
12. Angeles J. Fundamentals of Robotic Mechanical Systems. – New York: Springer, 2007. – 654 p.
13. Gupta J.K., Khurmi R.S. Theory of Machines. – New Delhi: Eurasia Publishing House, 2005. – 1120 p.
14. Singh V.P. Theory of Machines. – New Delhi: Dhanpat Rai Publications, 2008. – 980 p.
15. Po‘latovich, Sharipov Shuhrat. “The influence of the opening angle of the soil pusher of the combined machine leveler on its performance”. European Journal of Artificial Intelligence and Digital Economy” 1.2 (2024).
16. Po‘latovich S. S. The influence of the opening angle of the soil pusher of the combined machine leveler on its performance //European Journal of Artificial Intelligence and Digital Economy. – 2024. – T. 1. – №. 2. – C. 53-56.
17. Sharipov Shuhrat Po‘latovich. Determining the Driving Link of a Lever Mechanism // Journal of Architecture, Engineering and Modern Technologies. ISSN: 2181-3469. Volume 4, Issue 1, 2025. – pp. 18–21.
18. Sharipov Shuhrat Po‘latovich Effect of the Opening Angle of the Soil Pusher in a Combined Machine Leveler on Its Performance Indicators // International Journal of Recently Scientific Researcher’s Theory. – 2023. – Vol. 1, No. 3. – pp. 149–152.
19. Sharipov Shuhrat Po‘latovich, M. Ergashev. Improved Leveler of a Combined Machine // AGRO ILM. – Tashkent, 2022. – No. 3. – pp. 83–84.