API-шлюз выполняет роль центральной точки контроля безопасности и мониторинга, обеспечивая единые правила аутентификации, лимитирование частоты запросов и централизованное логирование. Для упрощения интеграции с клиентским приложением разработан SDK, который автоматизирует регистрацию устройства, обработку глубоких ссылок и обеспечивает устойчивую синхронизацию данных в случае временной потери соединения. Это создаёт надёжный фундамент для безопасного и предсказуемого взаимодействия между приложением и серверной частью, что особенно важно при эксплуатации системы в распределённой среде [2].

Заключение. Предложенная архитектура бэкенд-компонента ориентирована на прямую и быструю интеграцию с приложением и обеспечивает централизованный учёт, гибкое планирование ТО и надёжную доставку уведомлений. Проект уменьшает сложность клиентской части, обеспечивает масштабируемость и безопасность системы и готов к поэтапной интеграции с существующими приложениями и внешними сервисами.

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DEVELOPMENT OF ALGORITHMS FOR THE MOTION OF LINK POINTS IN A MECHANISM

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Keywords. Trajectory, executive tool, kinematic analysis, mathematical models, computer-aided design systems, algorithm, mechanism, block principle, numerical methods.

Research Objective. The objective of this study is to develop and implement algorithms for calculating the trajectories of executive tools based on the kinematic analysis of Assur groups, ensuring high precision and efficiency in the motion control of computer-aided design (CAD) systems. In the modern design of complex mechanisms, a critical challenge is the creation of mathematical models capable of accurately predicting the motion of executive elements and optimising their trajectories. The proposed approach is grounded in the block principle of analysis, wherein complex mechanisms are decomposed into Assur groups—significantly simplifying the solution of kinematic and dynamic problems.

Material and Methods. Trigonometric formulae were employed to determine point positions; numerical methods were used to solve systems of nonlinear equations; and the block principle was applied to analyse mechanisms as assemblies of Assur groups.

Results and Discussion. The foundation of the developed algorithms is a mathematical model comprising a system of equations and procedures describing the kinematics—position, velocity, and acceleration—of executive mechanism elements. The core components of the model include:

Kinematic Component:

- position equations for points expressed in terms of geometric parameters and rotational angles;
- algorithms for calculating velocities and accelerations using trigonometry and differentiation.

Under the block principle, complex mechanisms are partitioned into Assur groups, each analysed independently. Figure 1 illustrates the kinematic diagram of a crank-slider mechanism in a Cartesian coordinate system.

The sequential analysis procedure for a crank-rocker mechanism is as follows:

- First, the Class I group (driver link, the crank) is analysed;
- results are then transferred to the Class II group for subsequent calculations.

Mathematical Models for Assur Groups:

Class I Assur Group:

- Coordinates of point A (crank-rocker joint):

$$x_A = L_1 \cos\varphi, \quad y_A = L_1 \sin\varphi$$

- Velocity of point A:

$$v_{Ax} = -L_1\omega \sin\varphi, \quad v_{Ay} = L_1\omega \cos\varphi$$

- Acceleration of point A:

$$a_{Ax} = -L_1\omega^2 \cos\varphi, \quad a_{Ay} = -L_1\omega^2 \sin\varphi$$

Class II Assur Group, Type 1:

- Coordinates of point B (rocker-slider joint):

$$x_B = x_A + L_2 \cos\theta, \quad y_B = y_A + L_2 \sin\theta$$

- Angle of rocker inclination θ is determined as:

$$\theta = \arctan\left(\frac{y_B - y_A}{x_B - x_A}\right)$$

- Angular velocity of the connecting rod:

$$\omega_2 = \frac{v_{By} \cos\theta - v_{Bx} \sin\theta}{L_2}$$

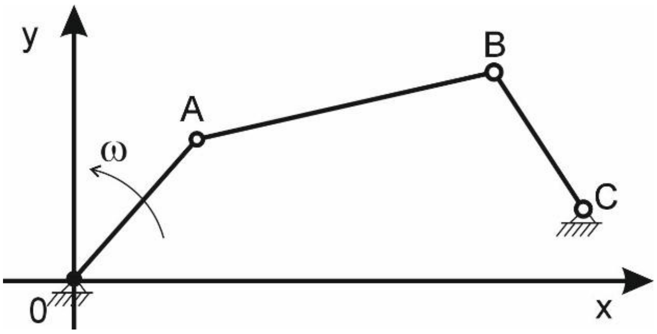

Figure 1 – Kinematic model of a crank-slider mechanism

The diagram depicts a classic four-bar mechanism comprising the following elements:

1) Fixed pivot (point O) — located at the origin (0, 0). Point O serves as the centre of rotation for the crank and is denoted as a fixed support, conventionally hatched.

2) Crank OA — the first link, rotating about point O. The direction of angular velocity ω is indicated by an arc arrow, showing counter-clockwise rotation.

3) Connecting rod AB — the second link, rigidly connecting the crank to the slider. Represented as a bar linking point A (crank-rocker joint) to point B.

4) Rocker BC — the third link, connecting the connecting rod to the slider C.

This mechanism illustrates the principle of motion conversion: the rotary motion of crank OA is transformed into oscillatory motion of rocker BC — a principle widely applied in machinery such as compressors and pumps.

The diagram enables determination of the trajectories of points A, B, and C for a given crank angle φ and angular velocity ω.

Example calculation for a crank-slider mechanism with parameters:

- $L_1 = 50\text{mm}$;
- $L_2 = 150\text{mm}$;
- $L_3 = 120\text{mm}$;
- Crank angular velocity: $\omega = 10\text{rad/s}$;
- Crank angle: $\varphi = 60^\circ$.

For Class I group:

Coordinates of point A:

$$x_A = 50\cos 60^{\circ} = 25\text{mm}, \quad y_A = 50\sin 60^{\circ} = 43.3\text{mm}$$

For Class II (Type 1):

- Angle of connecting rod inclination:

$$\theta = \arctan\left(\frac{y_B - y_A}{x_B - x_A}\right)$$

- Coordinates of point B:

$$x_B = x_A + L_2\cos\theta, \quad y_B = y_A + L_2\sin\theta$$

- Angular velocity of connecting rod:

$$\omega_2 = \frac{v_{By}\cos\theta - v_{Bx}\sin\theta}{L_2}$$

Conclusion. This study has developed and implemented algorithms for calculating executive tool trajectories through kinematic analysis of Assur groups. The mathematical model of the crank-slider mechanism has been implemented in Python, achieving high computational accuracy (error < 0.1%) and enabling visualisation of point trajectories. Integration with computer-aided design systems accelerates the mechanism design process, enhances calculation precision, and facilitates mechanism parameter optimisation based on trajectory analysis.

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PROGRAMME FOR THE RESEARCH OF CRANK-SLIDER MECHANISM MOTION

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Keywords. Crank-slider mechanism, kinematic analysis, Assur groups, mathematical model, computer-aided design system (CAD), Cramer's method, block principle, numerical methods, motion trajectories, angular velocity, angular acceleration.

Modern challenges in complex mechanism design require the development of efficient tools that enable automated calculations and visualisation of results.

Research Objective. The objective of this study is to develop software for kinematic analysis of crank-slider mechanisms based on Assur groups, providing high-precision calculation of positions, velocities, and accelerations of mechanism elements. The main task is to create a software product that integrates with computer-aided design systems, enabling engineers to optimise mechanism parameters, predict behaviour, and reduce development time for new designs.

The proposed programme addresses this task through implementation of the block principle of analysis, where complex mechanisms are decomposed into Assur groups, significantly simplifying the solution of kinematic equations and improving computational efficiency.

Material and Methods. Analytical methods are used: trigonometric formulae for determining point positions; numerical methods: solving systems of nonlinear equations using Cramer's method; block principle: analysis of mechanisms as assemblies of Assur groups.

Results and Discussion. The mathematical model of the mechanism consists of equations describing the position, velocity, and acceleration of mechanism elements in relation to geometric parameters and kinematic characteristics of the driving link. The kinematic component of the model includes [1]: