Parameterization for addressing tasks on flat lever mechanisms kinematic analysis in the AutoCAD environment

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Abstract. The objectives on identifying all the links' position in a flat lever mechanism within the considered time period, as well as determining the values of displacements, speeds and accelerations for the mechanism's characteristic points are applied in engineering calculations in the course of the mechanisms designing process. Conducting kinematic analysis using the graphoanalytic method is a fairly accurate and visual method in training, but it is quite time-consuming and contains a lot of routine operations. This paper demonstrates a solution enabling to significantly reduce the number of routine operations by creating a dynamic block for the mechanism's initial position with the parametric dependencies setting up. Designing is performed in the AutoCAD environment. This solution will help to quickly and accurately build a set of the flat lever mechanism links' positions and display the characteristic curves for angular coordinates \( \phi \) and time \( t \). The algorithm for creating such a block, as well as the features of working with parametric models are described. The proposed method allows to introduce the research elements in studying the discipline "Theory of mechanisms and machines". By imposing dimensional and geometric constraints, one can trace their influence on changing kinematic diagrams of the path, speed and acceleration.

Keywords: graphoanalytic method, flat lever mechanisms, kinematic diagrams, parameterization, dynamic blocks, AutoCAD, theory of mechanisms and machines.

1. Introduction

The computer technologies development has significantly expanded the possibilities for the engineering development based on the classical approaches in conjunction with the capabilities of modern computer-aided design (CAD) systems. At the present stage, when developing design documentation, no engineering company can do without using software. At the same time, the tasks scope addressed in these systems keeps constantly expanding, allowing to significantly reduce the time spent on research, calculations, modeling and drawings production. Based on the fundamental principles for a specific subject area, the routine operations on building technical objects and systems are performed using the basic operations in CAD modules [1].

The basic part of the Working Curriculum is designed in a way, so that, prior starting the study of the discipline "Theory of mechanisms and machines" (TMM), students would have already mastered the user skills for multifunctional mathematical packages MathCAD, Maple, Mathlab, as well as basic competencies in CAD (AutoCAD, KOMPAS-3D, SolidWorks). In the conditions of the classroom time budget deficit, the research tasks implementation is reserved for independent work. One of the tasks faced by the students in the discipline study is to master the methodology and obtain the skills on conducting kinematic analysis of various mechanisms types.
The issues on application software use for ensuring the mechanisms kinematic research optimization are being actively considered in the scientific and pedagogical community. Information technologies are applied using the mathematical packages' capabilities – MathCAD, Maple, Mathlab Mathlab+Simulink, Model Vision Studium (MVS), VisSim, Dymola, Modelika [2], [3], [4], [5]. Individual teams create their proprietary calculation modules or software complexes that are used in the real design [6]. The advantages of these programs include the formalized programming language, as well as the benefits of using a vector view in building velocity and acceleration lay-outs and diagrams for the path, speed and acceleration. However, an additional graphic module is required for creating a mechanism drawing with the individual links' positions changing. Some authors describe in detail the use of CAD capabilities – KOMPAS-3D [7], T-Flex [8], SolidWorks [9], CATIA [10] – for creating the parameterized mechanisms schemes on the plane.

Among various mechanism types in the mechanical engineering, flat lever mechanisms are among the most common ones. In most cases, the flat lever mechanisms motion is periodic in nature. Therefore, kinematic analysis for this mechanisms type is performed for one period of their operation.

Using only the capabilities of the Drawing CAD drawing panel commands in AutoCAD when creating a diagram for the mechanism positions using kinematic layouts and diagrams, leads to a large number of routine operations that require creating many similar plottings. It should be noted, that the graphic methods themselves are sufficiently accurate and differ only in their application areas; therefore, they are important for establishing the basic principles for reflecting the motion laws through graphic images and can be used in performing technical calculations related to the mechanisms operation.

When executing a design in CAD on a plane or in a space, parameterization can be applied either by programming, or by the model's interactive constructing directly in the course of drawing. The law for building a separate mechanism's link may be imposed either in the process of creating this element's image, or by imposing restrictions (links) on the already built drawing/model's objects. The latter (variational) method is the most convenient among the presented methods. It significantly speeds up the design process and allows for errors in this process.

Drawing model objects parameterization in the CAD environment can significantly increase the complexity level for the tasks solved with its help [11], [12], [13], [17], [18]. Relationships and constraints between drawing objects form a parametric model, the elements of which continuously execute the specified mathematical dependencies. This model has the ability to change the ratio between individual surfaces without breaking the relationships between individual drawing elements.

We offer a comprehensive parameterization for the diagrams building related to the characteristic points motion path and velocity in the flat lever mechanism, depending on the mechanism positions diagram. This solution combines the methods related to kinematic layouts and diagrams into a single parameterized complex, thus creating an effective solution for determining the mechanism characteristic points' path, velocity for a preset motion of the master link.

2. Materials and method
To solve this task, we suggest using the parameterization method in AutoCAD. The drawing's automatic parameterization will help to increase the speed and reduce the complexity in creating a mechanism layout and graphs of its dynamic characteristics, and to significantly increase the complexity level in the tasks to be solved.

Parameterization is the process of creating relationships and applying constraints to a group of geometric objects. A parametric drawing contains a set of geometric objects combined with overlaid relationships and constraints. Relationships between objects are dependencies between parameters, for example, coordinates of these objects' points. Restrictions are dependencies between parameters of the same object or their equating to a constant value (constant). Relationships and constraints form a parametric model, the elements of which continuously form the preset mathematical dependencies. This model can change the shape without breaking the links between the elements.
Let's consider the building algorithm, as exemplified by a kinematic study of the slotting machine mechanism. This equipment is designed for planning vertically arranged planes, hollowing grooves and slots, while the actuating device performs a rectilinear reciprocating cutting movement.

Let us consider the individual stages of the study.

1. We draw the initial mechanism position according to the task (Figure 1a) and create a dynamic block on its bases, assigning dimensional linear dependencies to the links' lengths and the angle dependence to the crank position initial angle (Figure 1b). It is important to select the correct sequence of segments' end points' placing for further changing the block's parameter values with other links' length values. We lock the segments' ends at points A and D; and at points B, C, E, we set the parameter of the two points coincidence or the point's attachment to an object. The point S of the connecting rod's mass center is set.

2. In the block's editor, we create a property table for the angle value \( \phi \) with a variable pitching of 30°. For numbering the obtained positions of the point C, we set the user parameter N, to which we assign the values from 1 to 12 in the property table. We add the values \( N_u \) and \( N_l \) corresponding to the slider's upper and lower positions to the table. These indicators are determined according to the similarity theorem when measuring the \( \phi \) angle corresponding to these positions. As exemplified by a given mechanism, the end positions get the following values: \( N_u = 7,2, N_l = 2,8 \) (Figure 1c).

3. Within the drawing margins, we apply blocks with different values of the parameter N to a single insertion point. We get a plan on the mechanism positions for 14 values. The obtained values of the connecting rod mass centers in different positions \( S_n \) are connected by a spline. This curve shows the trajectory of the connecting rod's mass center during the crank-slider mechanism's operation (Figure 2a). Trajectories of the mechanism links' extreme points movement allow the designer to form a rational form of the case.

4. The next building stage is the diagram formation for the output link's (slider's) characteristic point motion path. To do this, in the block editor, we link the point E with a horizontal line with the prepared abscissa axis (time axis \( \phi, t \), on which we set points 1 – 12 sequentially with a constant pitch \( b \) corresponding to the selected scale coefficient. We assign a length parameter "\( a \)" to the horizontal line and mark the slider's motion points:

\[
a = 120 + N b
\]  

(1)
where 120 is the constant distance to the motion axis, mm; 
\( b \) is the selected length scale factor for the time axis, \( b = 15 \) mm.

We set the visibility state for the construction lines.

\[ \text{Figure 2. Plotting the mechanism positions lay-out and the slider's motion diagram} \]
\[ \quad \text{a) coordinates of the slider's motion point for the initial position, b) parameterization of the movements graph for all the positions.} \]

5. Taking advantage of perpendicular vectors representations, we make vector equations. To build a velocity diagram for the output link's characteristic point, we use the velocity diagram. Moving sequentially from the mechanism's input link of the output link, we determine the speed \( v \) of point E. To do this, according to the known formula, we determine the value of the speed \( v \) of point \( B_1 \) for the rotational kinematic pair:

\[ v_{B_1} = \omega_1 \cdot l_{AB}, \]

where \( \omega_1 = \frac{\pi n_1}{30} \cdot 0.05 \), hence

\[ v_{B_1} = \frac{\pi \cdot 130}{30} \cdot 0.05 = 0.68 \text{ m/s} \]

\[ \text{Figure 3. Parameterization of the slider velocity diagram and the law of its change} \]
\[ \quad \text{a) velocity vectors layout for the initial position, b) parameterization of the velocity graph for all the positions.} \]

The next step in the block editor is to draw a 68 mm segment in an empty space, lock the starting point, and impose a perpendicular relationship with the AB segment. As a result, we get a vector \( v_{B_1} \) (Figure 3a). Similarly, by assigning dependencies, we create the velocity vectors for the
corresponding points, and, after getting the velocity vector $\tau$, we connect it with the segments equality dependence with the velocity axis on the velocity diagram. After saving the block changes, all the images become updated and the values for all the mechanism positions are built $v_E$ (Figure 3b).

Similarly, acceleration layouts and diagrams are created. The velocities and accelerations of the mechanism links' characteristic points are the result of the kinematic analysis and are used for power, dynamic, energetic studies of the mechanisms – determining the driving forces (torques), the kinetic energy of the mechanism and its links, forces of inertia (inertia moments), reactions in kinematic pairs, which, in their turn, are necessary for calculating the strength, stiffness, stability and wear of the mechanisms and their links.

3. Results and discussion

By creating a such a dynamic block that includes the mechanism's initial position, the forces and accelerations lay-out for the output link's characteristic point in the current position, the motion and speed axis, by overlaying these blocks in one point and changing the $\phi$ parameter, one can graphically get, at any time, all the kinematic characteristics' values of the mechanism links positions. In addition, by changing the input parameters' values, it is possible to obtain the above mentioned characteristics for a mechanism of a similar structure with different ratios between the link lengths. These results can be used for researches on optimizing the mechanism links' dimensional parameters. The mechanism's output stroke can be reduced by 50% or more in case of an optimal combination of link sizes, speed and acceleration [14]. It can be proved by the examples presented in Figures 4-6, which show the influence of changing the length of the crank, the slotted crank plate and the connecting rod, while keeping the constant size for the other slotted crank plate mechanism links, on the output link's velocity. Based on the velocity diagrams, it is evident, that the output link's velocity change law is affected the most by an increase or decrease in the crank's length.

![Figure 4](image_url)

**Figure 4.** Study on the effect of the crank's length changing in case of a constant slotted crank plate's length (0.1 m), connecting rod's length (0.32 m) and distance between the axes (0.02 m). The crank length: 1 - 0.03 m; 2 - 0.05 m; 3-0.075 m.

- a) lay-outs of the slotted crank plate mechanism for 12 links positions ($\phi=60^\circ$), b) diagram of the output link (slider) characteristic point motions, c) diagram of the slider's velocity.
Figure 5. Study on the effect of the slotted crank plate's length changing with a constant length of the crank (0.05 m), connecting rod (0.32 m), distance between the axes (0.2 m). The slotted crank plate's length 1-0.7 m; 2-0.1 m; 3-0.15 m.  
   a) lay-outs of the slotted crank plate mechanism for 12 link positions (φ₀=60°), b) diagram of the output link (slider) characteristic point movements, c) diagram of the slider's speed.

Figure 6. Study on the effect of the connecting rod's length changing with a constant length of the crank (0.05 m), constant length of the slotted crank plate (0.1 m) and the distance between the axes (0.02 m). The crank's length 1-0.2 m; 2-0.32 m; 3-0.5 m.  
   a) lay-outs of the slotted crank plate mechanism for 12 links positions (φ₀=60°), b) diagram of output link (slider) characteristic point movements, c) diagram of the slider's velocity.
Currently, the kinematic analysis can be performed using various mathematical programs. A solution including the use of C# and MATLAB, as well as the application development, is presented in the papers [15], [16]. The article presents an alternative approach to the kinematic analysis using CAD parameterization tools. By linking the capabilities of the parameterization commands and building dynamic blocks in AutoCAD, a lay-out of the crank-slider mechanism positions was created. Due to imposing dependencies on the dynamic block, a visual image of the kinematic scheme with any crank motion pitch was obtained, thus enabling to create a positions lay-out with any number of intermediate points. Graphs for the output link's characteristic point displacements and velocity were created using a graphoanalytic method that differs from the classical methods for tangents and chords.

4. Conclusions
The above constructing execution automation makes it possible to design mechanisms' parametric structures with their further transfer to the program code, and create a software product based on them with the objectives on studying the mechanisms' structures. At the same time, the presented methods describe the design process, which is important for understanding the essence of designing mechanisms' structures. In addition, by changing the mechanism links' parameters, it is possible to build dependencies of their impact on the mechanism's kinematic properties and select their optimal values; generate recommendations on the parameters selection in the course of the mechanism synthesis for guaranteeing the absence of "dead" positions; form the output link motion path, being close to the harmonic one, create the most rational kinematic scheme, which allows to reduce energy costs during the equipment operation.

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