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Conceptual design of a novel mechanism with parallel kinematics based on Chebyshev's linkage

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Abstract *The mechanisms with parallel kinematics are applied to a significant extent in today's industry because of the advantage over the mechanisms with serial kinematics. But the size and shape of workspace as the main problem of parallel kinematic machine stands. The proposed mechanism has parallel kinematics and can achieve three degrees of freedom (DOF) with a moving platform. The considered mechanism is actuated with translation actuated joints and has three kinematic chains, which are the connection between the stationary base and the moving platform. The kinematic chains arrangement is set to allow the extension of one of the mechanism's horizontal axis. This means the proposed mechanism has one extended horizontal axis, meaning physical length is the only limitation. This characteristic is very important because of the shape and size of the workspace. The main characteristic of the proposed mechanism is the third kinematic chain, which is based on Chebyshev's mechanism and presents the passive translational rotary joint. Because of the mechanism complexity, it is necessary to simplify the kinematic model for further mathematical analysis.*

Keywords *parallel kinematics, extended axis, Chebyshev's mechanism, simplification*

1. INTRODUCTION

This paper presents the new conceptual design of a parallel kinematics mechanism with one extended axis. The mechanism presented in this paper represents the specific approach to designing a mechanism that can transform the rotary motion of linkages into the rectilinear motion of the desired point. The main idea of this paper is to propose a new concept of a parallel kinematic mechanism that can achieve all advantages of parallel kinematic mechanisms over serial ones and overcome some usual disadvantages of parallel kinematic mechanisms. The idea of using one extended axis has already been introduced. One of the examples is presented in [1], where are shown advantages of mechanisms with one extended axis. The mechanism proposed in this paper as well as the mechanism presented in [1], have 3DOF. It is important to note that the extended axis presented in the paper [1] is horizontal with actuated translation joints as well as in mechanisms like UraneSX [2]. However, many more mechanisms have extended the vertical axis or have a physical possibility for the vertical axis extension [3, 4]. Straight-Line Generators are the mechanisms that can transform the rotary motion of linkages into the rectilinear motion of the desired point.

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Many mechanisms are created for this purpose, some of which are Watt's linkage, Robert's linkage, Chebyshev's linkage, and Peaucillier inversor, shown in Fig. 1. [5]. Characteristic for mechanisms like Watt's, Robert's, and Chebyshev's linkage is the possibility of forming an approximately straight line [5].

These mechanisms make mistakes in straight-line forming, and only the Peaucillier inversor can form the perfect straight line [5].

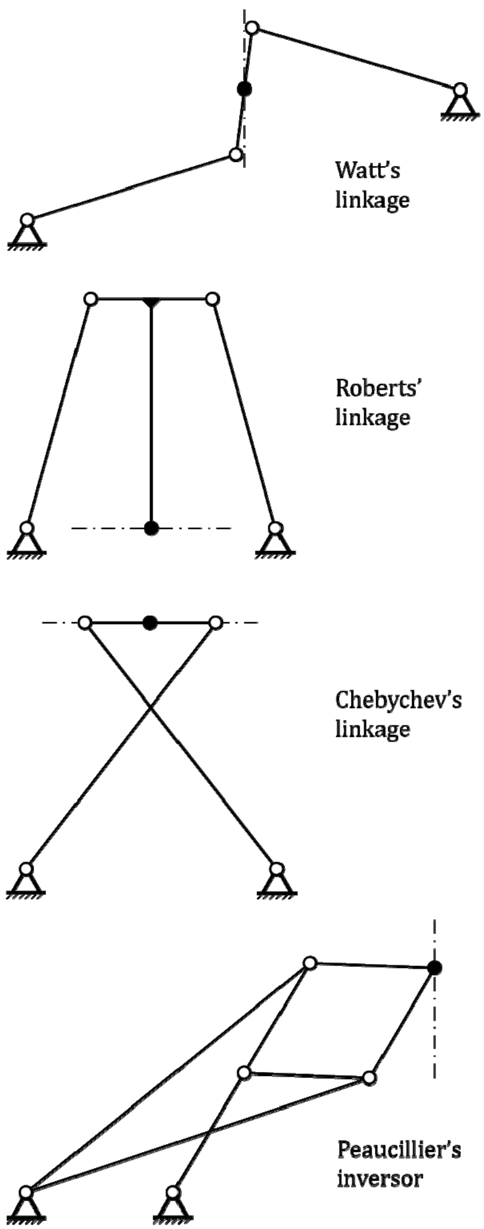

Fig. 1. Straight-line Generators [5]

Because of Peaucillier's inversor complexity and numerous required parts, this mechanism is complex for machining, but it is possible to use it, as shown in [1]. Chebyshev's linkage, the work of Pafnutii Lvovich Chebyshev, presents the best option for usage as part of the mechanism because of its simplicity, rigidity, and potential to form a straight line on one part of the moving trajectory.

Because of its simple design, Chebyshev's mechanism is often used as a part of some complex construction to generate a straight line. Applications of Chebyshev's mechanisms are often connected with vehicle construction as a suspension and wheel mechanism for special vehicles and robots [6, 7]. This paper presents the proposed mechanism's kinematic and simplified model acceptable for further analysis.

2. KINEMATIC STRUCTURE OF THE PROPOSED MECHANISM

The kinematic model of the proposed mechanism is shown in Fig. 2. Considered mechanism has 3DOF, and the moving platform (MP) is connected to a stationary base (SB) with three kinematic chains. The proposed mechanism has three independently actuated translation joints, and each translation joint allows 1 DOF. The motion of the MP results from the independent motion of each kinematic chain.

The proposed mechanism has two similar kinematic chains used for planar movements. The third kinematic chain is based on Chebishev's mechanism, and it is used to create the tridimensional motion of the MP.

The similar kinematic chains present the four-bar linked mechanisms connected in a shape of a parallelogram. Both four-bar linked mechanisms are connected to the translation joint on the SB on one mechanism side and to the moving platform from another. Every link of the four-bar mechanism is connected with another using the spherical joints, and every spherical joint allows 3 DOF. The four-bar linked mechanisms are arranged to cross each other without collision, and this arrangement is possible by rotating one of the mechanisms for 90°. The proposed arrangement of the four-bar linked mechanisms demands the complex MP shape but makes the proposed mechanism more stable and rigid.

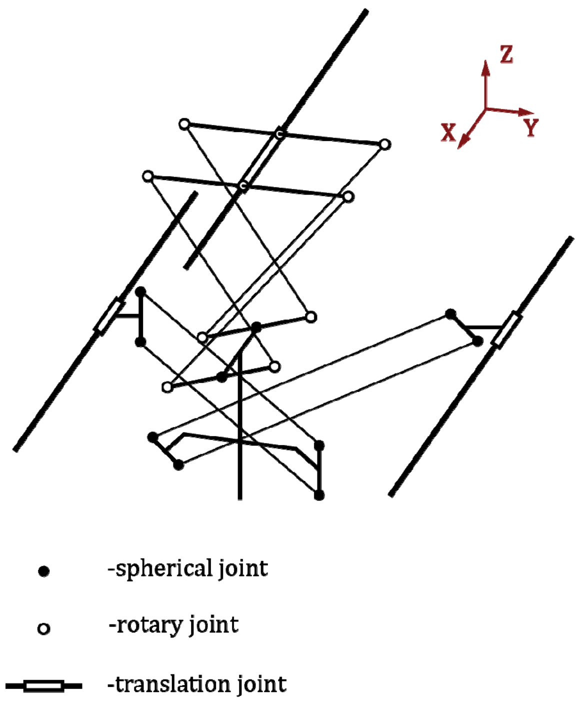

Fig. 2. The kinematic model of the proposed mechanism

As already said, the third kinematic chain is based on Chebishev's mechanism. The third kinematic chain is in the form of four connected elements. The first element is the translation joint on SB, and the second is part of the platform. The remaining two elements consist of Chebishev's mechanisms. Chebishev's mechanisms connect the translation joint on SB and the platform of the considered kinematic chain. Chebishev's mechanisms are connected to the translation joint on SB with one rotary joint, which allows 1 DOF. The connection between MP and Chebishev's mechanism is accomplished by using the spherical joints.
As previously mentioned, Chebishev's mechanism is the straight-line generator. This characteristic allows this mechanism to generate a straight line with the spherical joint connected to the platform. With this considered, Chebishev's mechanism presents the passive translational rotary joint, which allows the motion of the P point in the direction perpendicular to the motion of actuated translation joints.
Chebishev's mechanism consists of four connected links. The first link of Chebishev's mechanism is the smallest link of Chebishev's mechanism, which is connected to the MP with a spherical joint placed in the P point. The second link of Chebishev's mechanism is connected to the active translation joint with a rotary joint. The connection between the first and the second link of Chebishev's mechanism is accomplished with two crossed links. Links that connect the first and the second links of Chebishev's mechanism are the same length. The connection between every link of Chebishev's mechanism is accomplished using rotary joints. It is important to say that crossed links of Chebishev's mechanism are not in the collision.
For Chebishev's mechanism to generate a straight line, it is crucial to use the optimized lengths of every link used in Chebishev's mechanism. The mathematician Pafnuty Lvovich Chebyshev has established the proper proportion between links for the mechanism to work [1]. The dimension of the first, smallest link (a) is parametrized and has the value $a = h$. The second link (b) of Chebishev's mechanism has a dimension twice as big as the first one, $b=2*h$. The crossed links of Chebishev's mechanism have dimension: $c=2.5*h$. The Chebishev's mechanism with desiered proportion between links is showhn in Fig. 3.

3. SIMPLIFICATION OF THE PROPOSED MECHANISM

The proposed mechanism has a complex structure, and the complexity of the proposed mechanism is based on parallel kinematics. Mechanisms with parallel kinematics relative to the mechanism with serial kinematics have much more links used in construction.
The difference in link number is because the links of the serial kinematic machine are much heavier than those of the parallel kinematic machine. Because of the previously explained reason, parallel kinematic mechanisms have many links to establish stability and the rigidity of the construction.

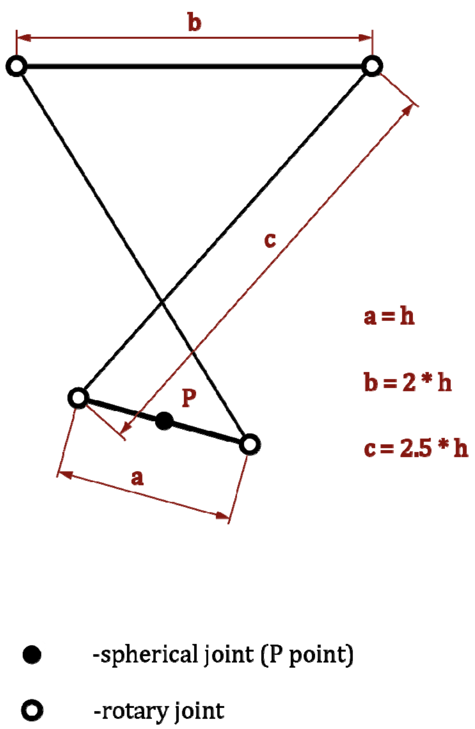

Fig. 3. The Chebishev's mechanism

To design the physical model of the proposed mechanism, it is important to analyze the workspace of the mechanism. Kinematic equations are needed for workspace analysis. The kinematic equations present the mathematical model of the mechanism and are established using the wireframe representation of the mechanism.

The representation of the mechanism structure shown in Fig. 1 needs to be simplified for analysis. The simplification process needs to be done in a way to keep the simplified mechanism possible to move the same way as the original mechanism. This process enables the creation of the mathematical model of the machine, which is crucial for future mechanism research.

As previously said, the proposed mechanism contains three kinematic chains. The first and the second kinematic chains are similar, which means that the connection between those two kinematic chains and MP, as well as between those two kinematic chains and SB is the same. The only difference between the first and second kinematic chain is their arrangement. The second one is rotated for 90° relative to the first kinematic chain.

The simplification of one of the similar kinematic chains is shown in Fig. 4.

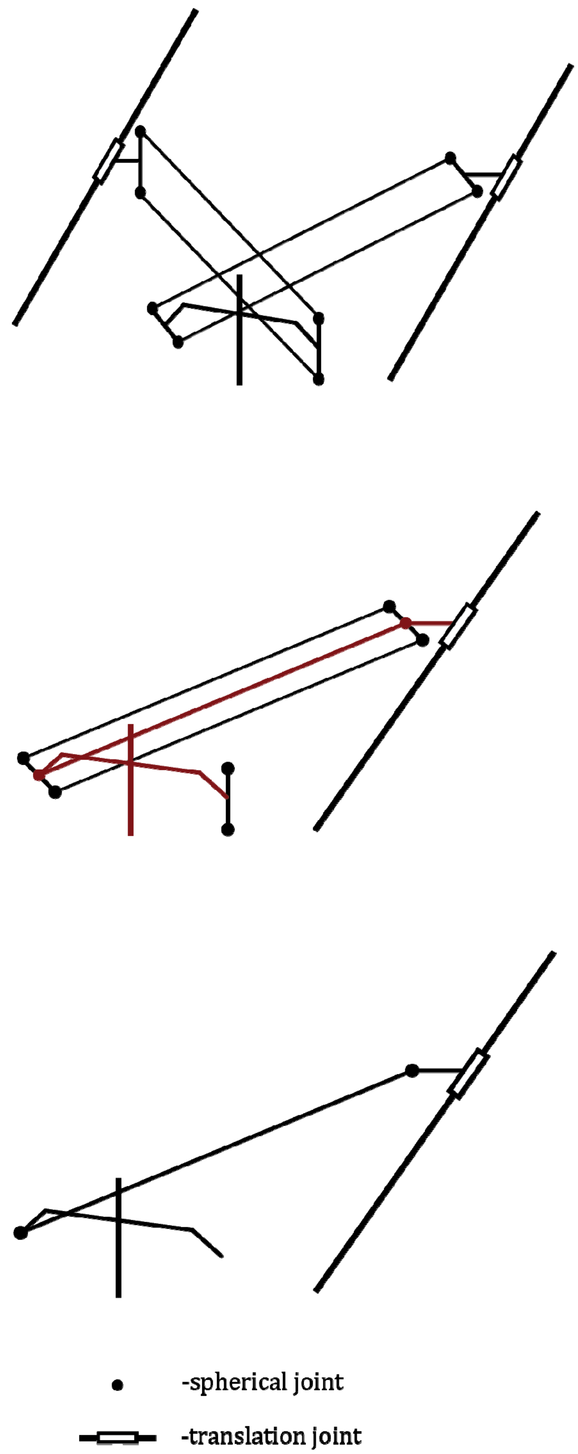

Fig. 4. The simplification process of one of the similar kinematic chains

The idea is to reduce the number of links from four to one. With this, the considered kinematic chain becomes more suitable for kinematic analysis.
As well as simplifying the similar kinematic chains of the proposed mechanism, it is important to perform simplification in the third kinematic chain. The third kinematic chain, as already said, is based on Chebishev's mechanism. The third kinematic chain consists of four elements, two of which are Chebishev's mechanisms. The simplification process is similar to the process performed on similar kinematic chains. The idea is to replace four elements with only one as a representation for kinematic analysis purposes. The simplification process of the third kinematic chain is shown in Fig. 6. and the simplified model of the proposed mechanism is shown in Fig. 5.
The one element which replaces the four elements presented in the original version is Chebishev's mechanism.

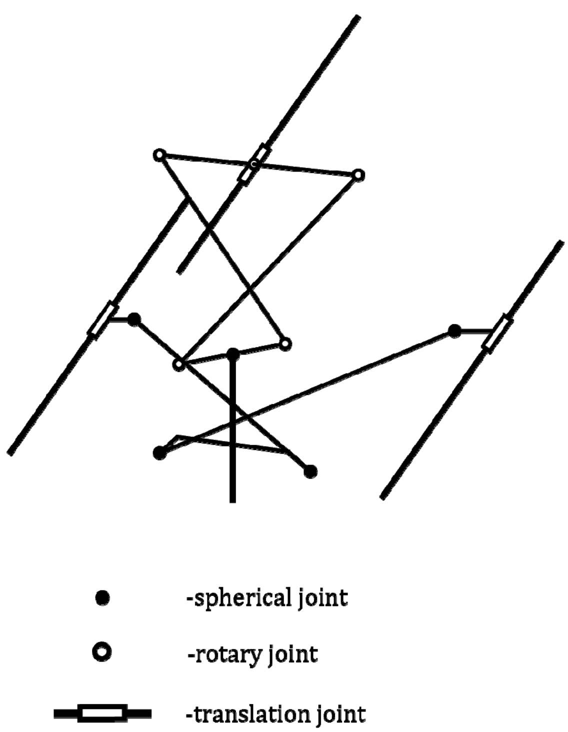

Fig. 5. The simplified model of the proposed mechanism

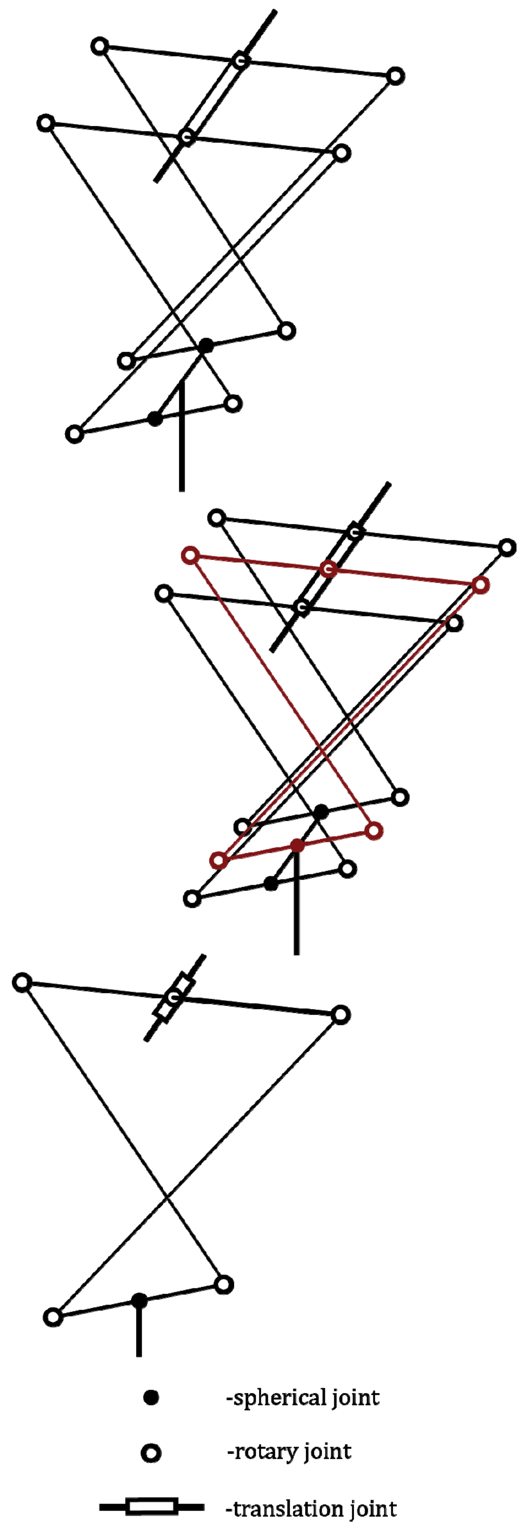

Fig. 6. The simplification process of the third kinematic chain

Whit simplification of all three kinematic chains of the proposed mechanism is possible to generate a model of the mechanism more suitable for kinematic analysis. With proposed simplification the foundation for future research is formed.

4. CONCLUSION

The mechanism presented in this paper offers a new conceptual design. The extended horizontal axis of the mechanism provides numerous possible usages in different industries. The proposed mechanism can be used as a machine tool for the milling process with the horizontal or vertical orientation of the main spindle. The usage of the proposed mechanism can be found in the wood industry with an extended horizontal axis as the advantage over serial machines. The proposed mechanism usage is also possible in additive manufacturing, laser engraving, and other engineering areas. The rigidity and stability of the proposed mechanism have the potential to be very high, and yet the mechanism construction is not robust and heavy. The proposed mechanism has numerous links specifically arranged, which are not large and heavy, further confirming the previous statements.

Geometric model analysis and simplification of the mechanism structure presented in this paper are the base for further research. This means that the presented structural design is not final, and some structural changes might be provided by details gained from future research. Future research will be focused on the kinematic model of the mechanism. The main idea will be to optimize the parameters of the machine to get the most acceptable size and shape of the workspace, as the weakest characteristic of parallel kinematic machines.

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