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VERIFICATION OF KINEMATIC JOINTS ON A PHYSICAL PROTOTYPE OF A NOVEL PARALLEL MECHANISM BASED ON CHEBYSHEV'S LINKAGE

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Abstract: *Developing a novel parallel mechanism design is a complex process, including multiple phases. Designing and analyzing the mechanism's physical prototype is one of the most important phases. The proposed mechanism is novel, with parallel kinematics with actuated translation joins. The considered mechanisms platform has three degrees of freedom (DOF) achieved with three independent kinematic chains representing the connection between the stationary base and the moving platform. The proposed mechanism has numerous connected linkages because of the parallel kinematic construction. The weakest parameter of the mechanisms with parallel kinematics compared to mechanisms with serial kinematics is the shape and size of the workspace. Because of this, the workspace is one of the main parameters in designing a mechanism with parallel kinematics. To achieve the optimal workspace, it is necessary to use the proper joints in the mechanism construction. The mechanism analysis and proper joint selection can be achieved in two ways. The first way is to build the virtual model and experiment on it, and the second is to build the physical prototype. The best way to select the proper joints for the mechanism construction is to compare the analysis results of virtual and physical mechanisms. If the results of comparing virtual and physical prototypes are the same, the physical prototype verifies the mechanism design.*

Keywords: *Parallel mechanism, Chebyshev's linkage, Physical prototype, Workspace, Verification.*

1. INTRODUCTION

Hexaglide and Triaglide mechanisms are examples of workspace extension achieved by extending one axis as a principal motion axis, a common feature of all serial kinematic machines. With the idea of extending one axis of motion, a new 3 DOF parallel kinematic mechanism has been developed with a specific passive translation rotary joint [1]. The mechanism with parallel kinematics shown in [2] presents the mechanism with an extended horizontal axis. It has the ability to transform the rotary motion of the linkages into the rectilinear motion of the desired point. The proposed mechanism's main characteristic is the passive translation rotary joint [1, 2]. In the case of the proposed mechanism, Chebyshev's linkage has the function of a passive translation rotary joint. An example of a developed solution for an industrial machine with parallel kinematics is the LOLA pn101_4 [3], which uses a passive translation rotary joint in its kinematic chain. The mechanism concepts with specific solutions of passive translation rotary joints were also considered for this machine [1].

The parallel construction of the mechanism and usage of Chebyshev's linkage, the proposed mechanism has numerous linkages connected with multiple joints. Because of the mechanism's complexity, the development of the mechanism design is a complicated process. The first thing in the developing process is choosing the right joints that can guarantee the mechanism's proper motion. The joints greatly impact the workspace, which is the main parameter of the mechanisms with parallel kinematics, and because of that, it is necessary to verify the mechanism's movements. For the verification of the mechanism's movements, it is essential to create the mechanism prototype. Construction of the required prototype can be expensive and time-consuming but of huge importance to the mechanism design [4, 5].

A virtual prototype of the proposed mechanism is created to verify the movements of joints. Also, for verification of the proposed mechanism is used physical prototype of the proposed mechanism. Fused deposition modelling (FDM) is used to fabricate the physical prototype. FDM is one of the most used additive technologies (AT). The advantage of AT is the ability to save time in the design and development process. AT is used for quickly fabricating functional models, physical prototypes and small series of parts directly from CAD models [6, 7].

This paper is dedicated to explaining the proposed mechanism's functionality with an accent on the kinematic connections between rigid components. Because of the mechanism complexity, every kinematic chain is explained separately, with special attention on Chebyshev's linkage. The mechanism movements are tested on created prototypes of the proposed mechanism. The final verification is accomplished by comparing the movements of the virtual and physical prototypes.

2. THE KINEMATIC STRUCTURE OF THE PROPOSED PARALLEL MECHANISM BASED ON CHEBYSHEV'S LINKAGE

The proposed mechanism has three kinematic chains which form the connection between the moving platform (MP) and stationary base (SB), shown in Fig. 1. The MP can achieve three degrees of freedom (3 DOF) in the mechanisms' workspace. Each kinematic chain is connected to the SB with one actuated translation joint (s_1, s_2 and s_3). The connections between the kinematic chains and MP and between the links of each kinematic chain are connected with passive joints.

The movement of each translation joint has the direction of the mechanism's extended axis. The first and the second kinematic chain has the shape of a simple parallelogram. The active translation joint connects the first and the second kinematic chain to the SB. The connection between the first kinematic chain and MP, as well as the connection between the second kinematic chain and MP, is achieved with two spherical joints. Each spherical joint has 3 DOF. Each parallelogram is built with four rigid components connected with spherical joints.

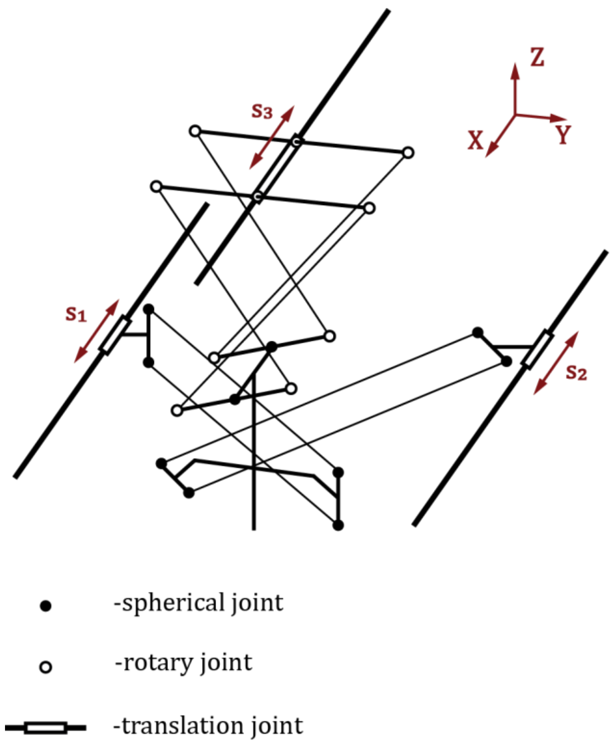

Figure 1. Kinematic model of the proposed mechanism [2]

The first rigid component has a specific shape, and it is used to connect the parallelogram and translation joint. The second and third rigid component are simple links, and the fourth rigid component of the parallelogram is part of the MP. The main difference between the first and the second kinematic chain is in the shape of the first and fourth rigid component.

The first and second kinematic chains are oriented to cross each other without collision. The second kinematic chain is rotated for 90 degrees in relation to the first kinematic chain. This arrangement of the first and second kinematic chains is why the chains are not in collision.

The third kinematic chain is based on Chebyshev's linkage and completes the 3D motion of the MP. This kinematic chain is also the four-bar mechanism, which has the shape of a parallelogram. The first component of the third kinematic chain is the translation joint. The second and third components of the third kinematic chain are Chebyshev's linkages. The connection between the translation joint and Chebyshev's linkages is provided with a simple rotary joint (1 DOF). The third kinematic chain's fourth component is the MP part. The MP and Chebyshev's linkages are connected with spherical joints.

3. VERIFICATION OF THE CHEBYSHEV'S LINKAGE

As already mentioned, the proposed mechanism is based on Chebyshev's linkage, shown in Fig. 2 and Fig. 3. In the mechanism construction, the Chebyshev's linkage is a part of the four-bar mechanism, but the Chebyshev's linkage is a four-bar mechanism itself. The main difference between the previously explained four-bar mechanisms and Chebyshev's linkage is the arrangement of the components. The Chebyshev's linkage does not have the shape of a parallelogram.

The Chebyshev's linkage is a Straight-line generator, which has the ability to transform the rotary motion of linkages into the rectilinear motion of the desired point (P) [8].

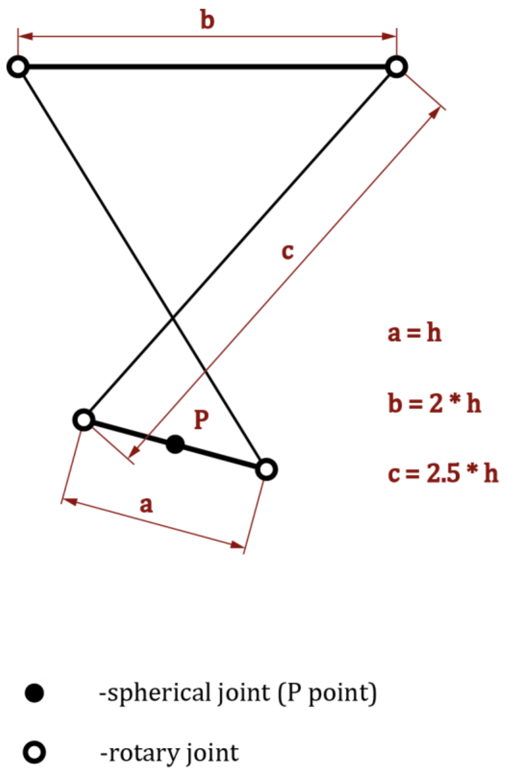

Figure 2. The Chebyshev's mechanism [2]

For the future explanation, the value *h* is the constant parametric variable. The first rigid component of Chebyshev's linkage has a length equal to 2h (b = 2*h). The second and third components are crossed without collision and have the same length (c = 2.5*h). The value of the last component of Chebyshev's linkage equals h (a = h). All connections between components of Chebyshev's linkage are rotary joints.

One simple design is produced using the 3D additive machine to test the functionality of the Chebyshev's linkage, shown in Fig. 3. PLA is the material used for additive manufacturing of the simple design of Chebyshev's linkage. The machine used for additive manufacturing is Velleman Vertex K8400, which possesses 3 DOF achieved with Cartesian serial kinematics [9].

This simple design of Chebyshev's linkage is produced to show that it is possible to generate a straight line with this mechanism. Fig. 3 shows that a straight line is generated by moving the pencil fixed in the P point of Chebyshev's linkage.

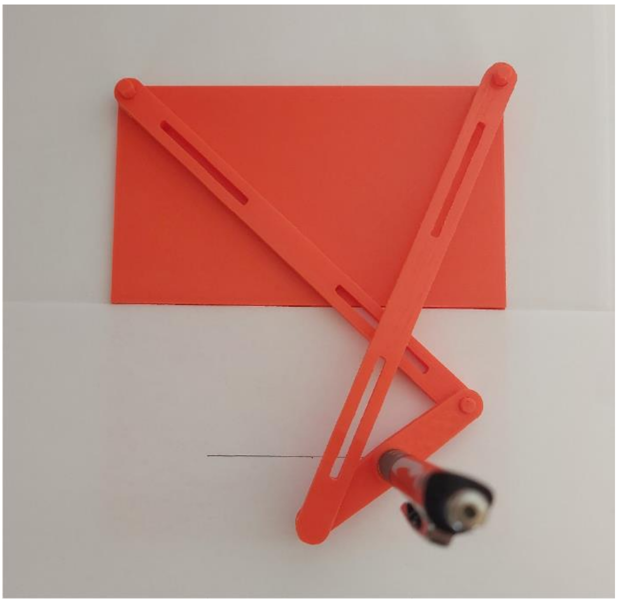

Figure 3. Verification of the Chebyshev's linkage

4. PROTOTYPES OF THE PROPOSED MECHANISM

As already mentioned, two prototypes are created to verify the functionality of the proposed mechanism, shown in Fig. 4 and Fig. 5. The first is a virtual prototype, and the second is a physical prototype.

4.1 The virtual prototype of the proposed mechanism

The virtual prototype of the proposed mechanism is designed using the PTC Creo Parametric software. A 3D model of the proposed mechanism created in this software is used for virtual tests of the mechanism. A created virtual prototype includes all previously explained connections between mechanisms components. The command Pin is used to define a simple rotary joint in a virtual model of the mechanism, which enables the rotation around the desired axis. The second used command is command Ball, which defines the spherical joint and enables rotation around the desired point. The last used command is Slider. This command enables the translation movement along the required axis in a defined movement range.

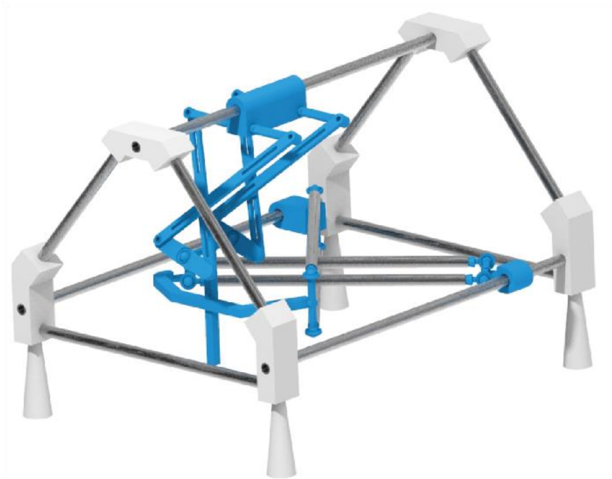

Figure 4. The virtual prototype

All relationships between mechanism components are tested using the created 3D model. The results of the virtual prototype tests show that the mechanism is working properly without breakdowns. The 3D model of the proposed mechanism created in PTC Creo Parametric is shown in Fig. 4.

The mechanism configured in this way can also be used to simulate the work of the mechanism according to the given program [10] to check the mechanism's possibility and potential collisions within the workspace's limits.

4.2 The physical prototype of the proposed mechanism

The second prototype is the physical prototype, shown in Fig. 5. This prototype is created using the information from the virtual prototype. Because of this, the physical prototype has the same dimensions as the virtual prototype.

The components of the physical prototype are steel tubes and plastic components manufactured using the Velleman Vertex K8400 3D printing machine. The physical prototype is built to allow all passive motions between components. Tests on a physical prototype are done by moving all mechanism components and observing the resulting movement of the machine. The result of the testing shows that the mechanism is working as expected.

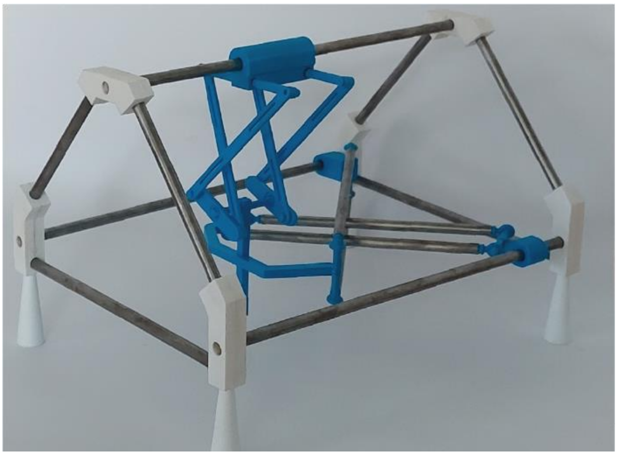

Figure 5. The physical prototype

The final verification of the proposed mechanisms is done by comparing the mechanism's virtual and physical prototypes, shown in Fig. 6. This comparison is made by moving the MP of both mechanisms to similar characteristic points and confirming that both mechanisms are moving in the same way.

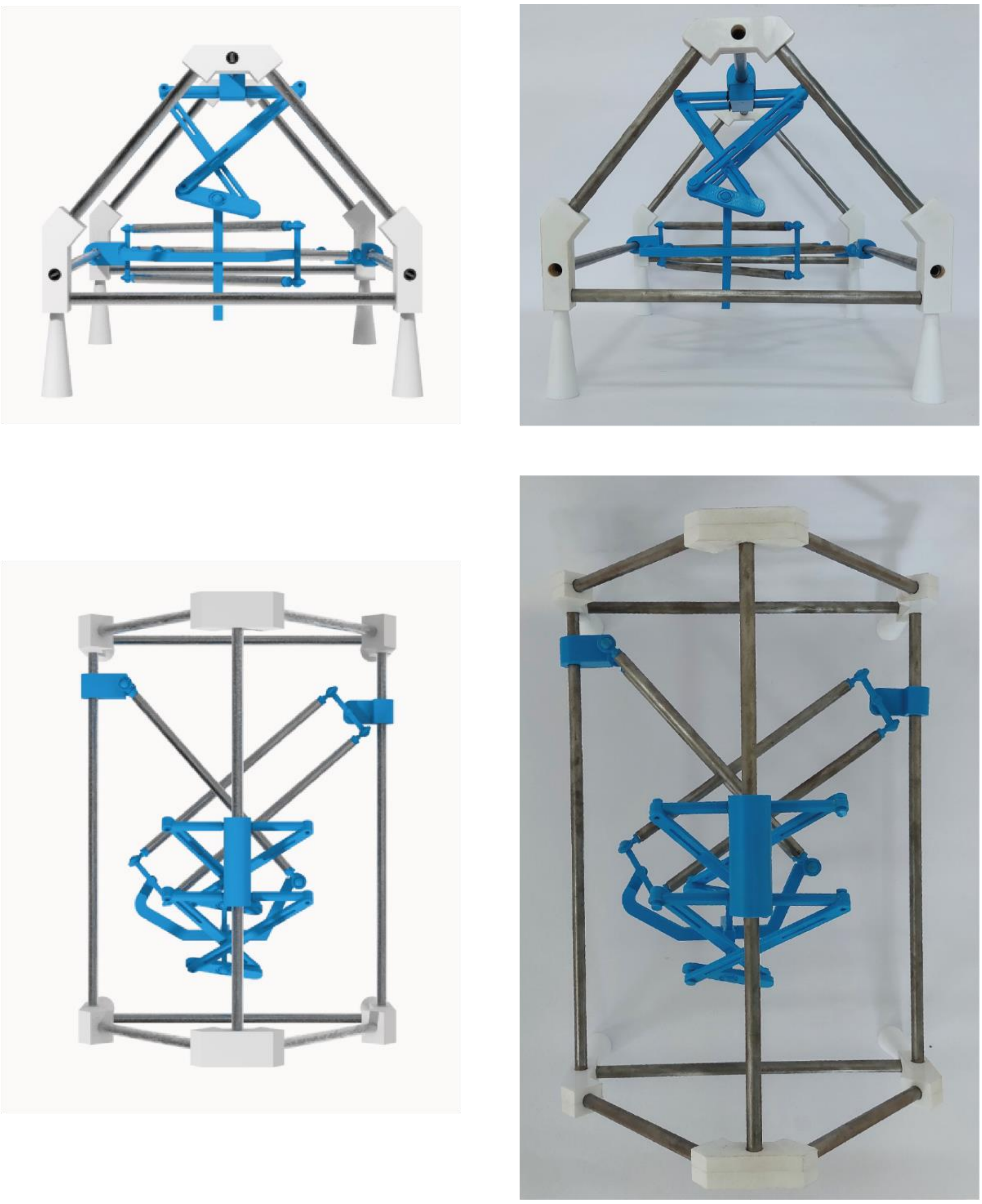

Figure 6. The virtual and physical prototypes

5. CONCLUSION

This paper has shown that the proposed mechanism is moving as expected, which is concluded with testing on virtual and physical prototypes. The tests are done separately on each prototype, and the results confirm that the used joints are correctly selected and positioned.

Also, the important point is that the virtual and especially physical prototype has shown some areas for improvement in the mechanism construction. The first point is the shape of the MP, which can be improved to enable the movement of the MP in a much larger workspace. The second one is the possibility of using the joints with 2 DOF on some points where the spherical joints (3 DOF) are now. This can also allow the bigger workspace of the mechanism. This procedure still needs to be implemented because the 2 DOF joints require much larger precision than the Used 3D printer can achieve.

The one point that needs to be considered is the links' dimensions, but it is essential first to solve the Inverse kinematic problem. Also, one of the main points in future research will be the proposed mechanisms orientation (horizontal or vertical guideways), which will greatly impact future mechanism construction. The main parameter that will define the mechanism's orientation is the workspace.

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