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A MOTION SIMULATION OF A TECHNICAL MEAN USING ELEMENTS OF A FLEXIBLE BODY TYPE

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Abstract: The work presents a motion simulation of a technical system in which one of the elements of a system (deciding on the correct operation of the movable element) can be deformed. The use of flexible body elements for the working simulation of the system, allows a verification of the geometrical form and dimensions of its elements, in the context of the assumed trajectory of the motion. Based on the obtained simulation results, it is possible to make constructional changes in the area of the analyzed system so that its movement trajectory was consistent with the assumed one. One should noted, that described virtual studies concerned on the analysis of the tripod system. This system consists of a frame, three electric motors of a rotary motion integrated with a helical gear, a movable platform and a bars set. As a result of the conducted research, the geometrical form of the support frame of the system was modified to the form in which an acceptable positioning error was obtained.

Key words: CAD/CAE systems, motion simulation, flexible body, tripod, modeling.

1. INTRODUCTION

A motion simulation of a virtual model of the technical system in the multibody system environment is usually based on the assumption that all its elements are rigid bodies [1-3, 6, 7, 11-13, 17-19, 21, 22]. In this case, the kinematics and dynamics of the system elements, which are considered as non-deformable elements, are analyzed. The numerical analyses, carried out in this way do not take into account the influence of the deformation of the system components, caused by their mutual interactions, on the obtained results of the simulation. Determining the value and course of occurrence of a positioning error of a moving element of the system resulting from its constructional form is very important due to two aspects. The first aspect includes issues related to the modification of the geometrical form of the system to ensure the lowest possible positioning error of the moving element. The second aspect is related to the identification of the positioning error in order to transfer information about the error to the machine control system. In the first case, it is possible to modify the geometric and material form so that the system is characterized by sufficient stiffness at which the assumed positioning error is obtained. In the second case, it is possible to select such control parameters that will allow the assumed operation of the system despite the occurring disruption in the form of deformation of the support system in relation to the assumed maximum positioning error of the machine moving element. In this case, it is necessary to transfer the obtained information about the current error of the location of the movable element relative to the assumed motion trajectory to the control system (Figure 1).

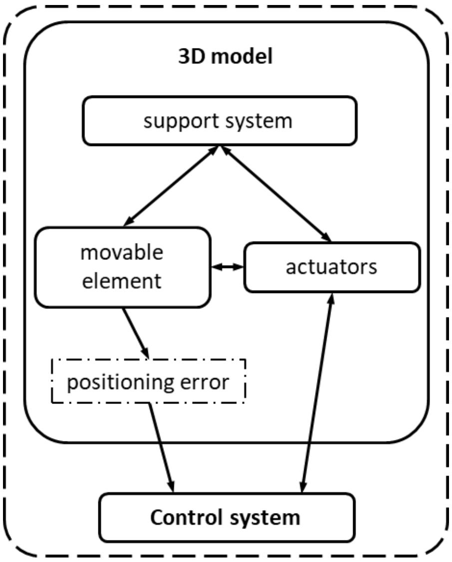

Fig. 1. The conception of the integrated model of the tripod in the control context

Based on the information received, the operation algorithm of the control system could provide a way to control drives to minimize the positioning error of its moving element. The paper presents research constituting the first stage of activities related to the creation of an integrated tripod model in the context of control, according to the methodology presented in the works [4, 5, 8-10, 14-16, 20]. The conducted research referred to the determination of the positioning error of the tripod executive element assuming that the support system is a deformable element.

2. RESEARCH OBJECT

Research on the impact of the system stiffness on the positioning errors of its moving element was carried out in relation to the tripod system. In the area of the considered system, the executive and the control subsystems can be distinguished (Figure 2).

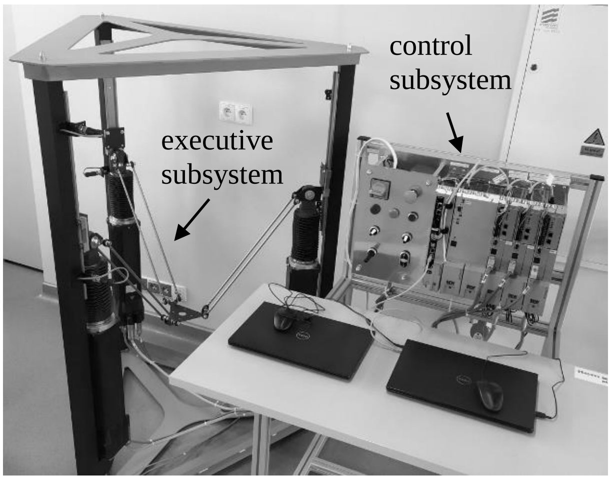

Fig. 2. The analized tripod system

The executive subsystem consists of the frame, three electric motors of rotary motion, integrated with a helical gear, the mobile platform and rods system. Electric motors form the executive system of the distributed control system (Figure 3). The movable platform is connected to individual servo drives using rods with application the ball joints. The movable platform can move linearly relative to the three coordinate system axes and angularly relative to the two coordinate system axes.

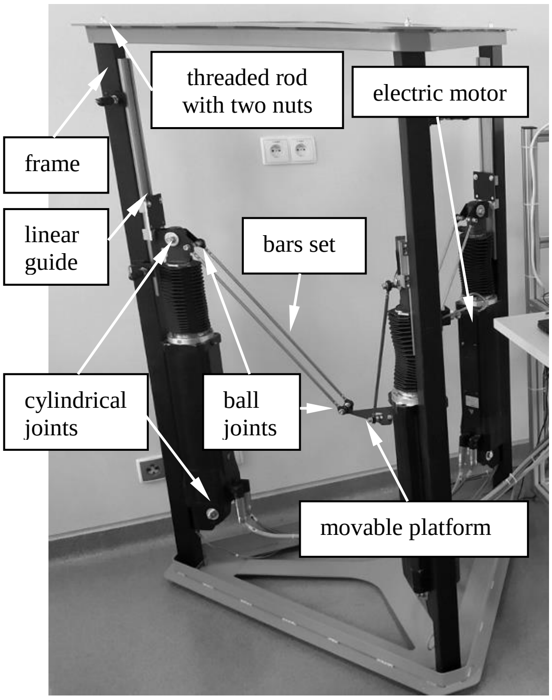

Fig. 3. The analized executive subsystem

The most important components of the control system are: PLC controller and three SEW Eurodrive inverters, by means of which drives are controlled.

3. PREPARING THE TEST SYSTEM MODEL AND ITS MOTION SIMULATION

The 3D model of the analyzed system prepared for motion simulation was created in PLM Siemens NX software. In the first step, in order to determine the movable platform reference trajectory, all model elements were defined as stiff bodies (Figure 4). The following major component groups are defined in the model prepared to the motion simulation:

- of the "Links" type, which describe the geometric form of individual elements of the analyzed model and their physical properties such as: mass, center of gravity or moments of inertia,
- of the “Joints” and “Constraints” type, which define the way of cooperation between components of the type “Links”,
- of the "Driver" type, by which the model of the work of tripod drives is described in the model (by reference to the corresponding components of the type "Joints").

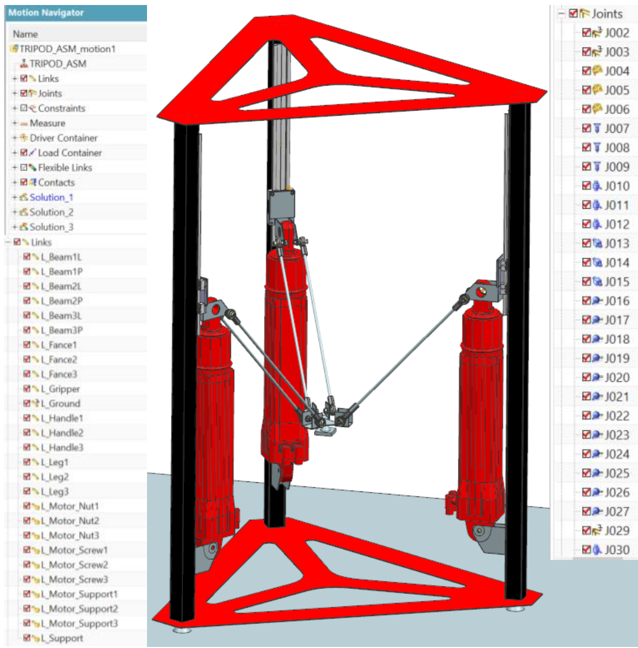

Fig. 4. The 3D model of the tripod system prepared for the motion simulation

In the research was assumed the character of the work of selected drives as shown in Figure 5. It has been assumed that two drives will run simultaneously with a maximum speed of 18000deg/s. The model also takes into account the ratio resulting from the use of helical gears (one turn of the screw corresponds to a linear displacement of 6mm on the drive piston rod). In the studies, a simulation time of 1 s was assumed. Due to the adopted conditions of system simulation, in 1 s, the piston rod will move in a linear motion over a distance of 300mm.

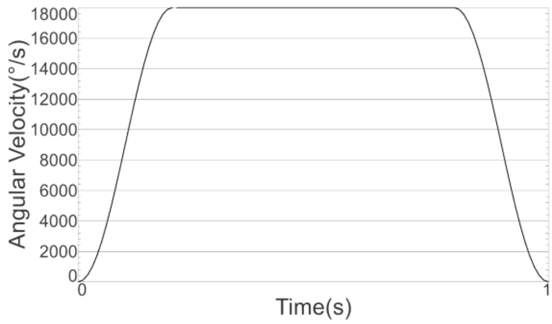

Fig. 5. The definitin of drives

Displacement of drives of the analized system makes the displacement of the movable platform, as presented in the Figure 6.

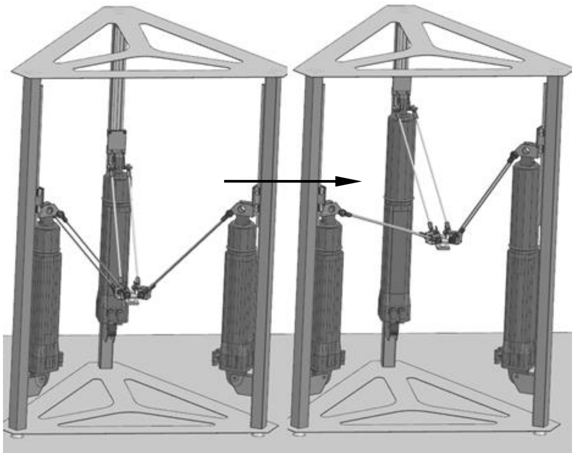
Fig. 6. The displacement of the movable platform

Based on the motion simulation the displacement characteristic of the movable platform was created (Figure 7).

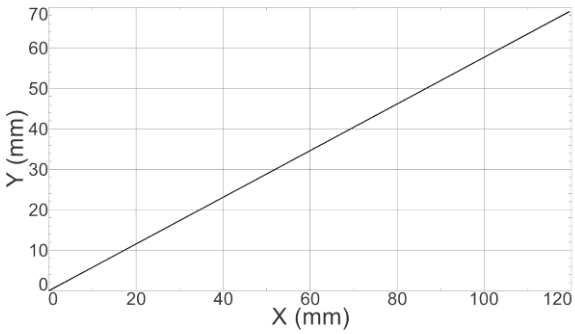

Fig. 7. The displacement characteristic of the movable platform (all body as rigid bodies)

The created scheme presents the displacement of the movable element in the X-Y plane. The obtained characteristic shows the trajectory of the moveable element of the system, assuming that all elements of the system are treated as stiff bodies. The discussed characteristic was considered as the basic characteristic to which the results of the system simulation will be referred, where the selected elements are defined as deformable.

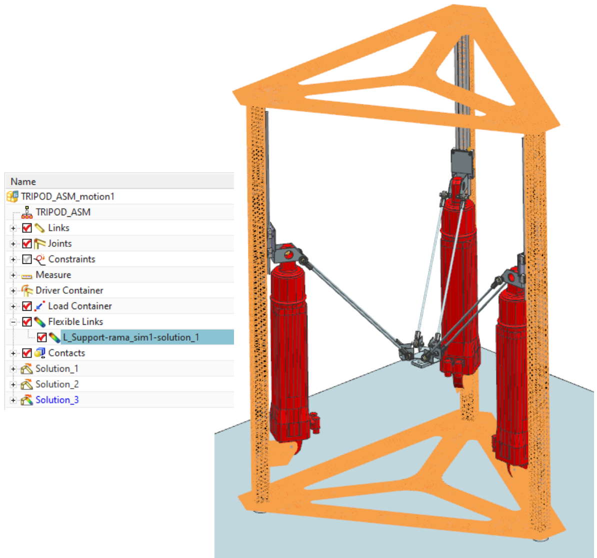

Fig. 8. The definition of flexible body type element

In the next step, the element of the system, which has the most important influence on the positioning error of the movable platform, was chosen. In this case that element is the frame (Figure 8), because it is the support system of the three motor drives, and the deformation of the element generates the moving error of all elements of the system. In order to prepare the model consisting of the flexible body and rigid bodies to the motion simulation, the FEM analysis of the frame was performed.

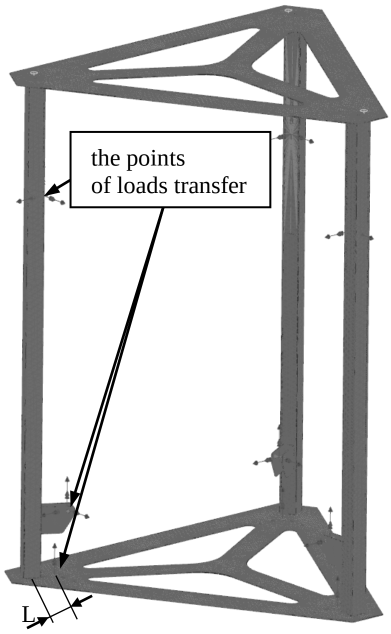

Fig. 9. The defined boundary conditions in relation to the frame element

In the FEM analysis a particular attention was paid to the proper definition of boundary conditions (Figure 9). When defining the boundary conditions in relation to the frame model, it was very important to define elements enabling the information transfer of about occurring loads during the operation of the tripod system to the FEM model. It was equally important to include these elements in the area of given constraints of the model of the system prepared for motion simulation. In order to determine how the frame behaves during the system operation, it was also necessary to determine the frequencies of natural vibratons of the element, taking into account the boundary conditions and material characteristics. In the FEM analysis was assumed that the frame element was manufactured from a steel.

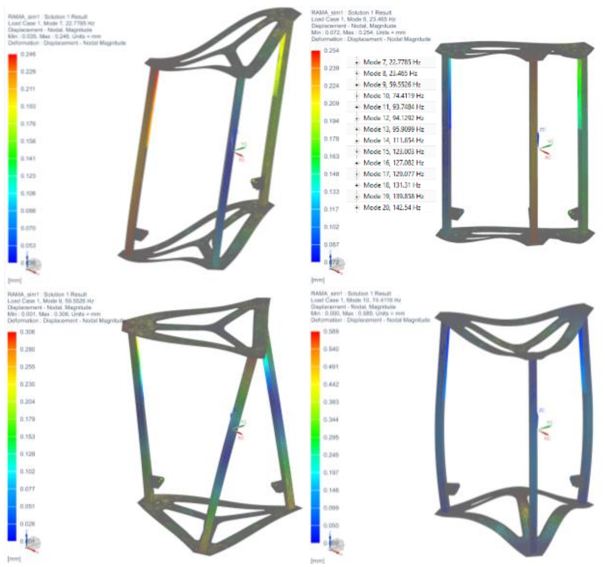

Fig. 10. Determining the frequencies of natural vibrations

In Figure 10 the four chosen frequencies of natural vibrations of the frame was presented. Then the motion simulation was performed, where the frame element was considered as the flexible body (based on the obtained model of the frame element from the FEM analysis). The result of the displacement characteristic of the movable platform in X-Y plane is shown on the Figure 11.

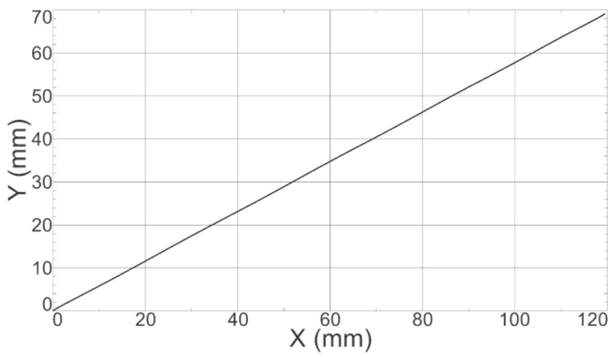

Fig. 11. Displacement characteristic of the movable platform (frame as a flexible body)

Presented displacement characteristics of the movable platform are very similar, but between them can be observed differences. The comparison of those analyzed cases was shown in the Figure 12. The maximal distance between the characteristics is 0.15mm. The distance was named as the positioning error.

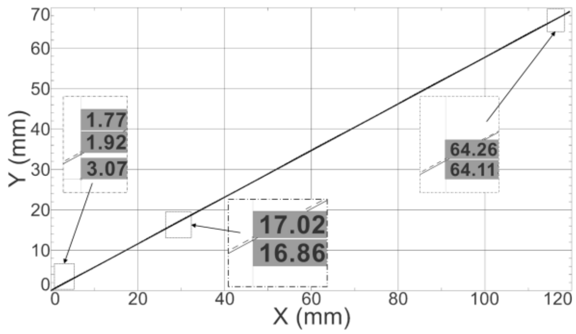

Fig. 12. The comparison of the characteristics of the movable platform

The occurring positioning error of the movable platform is associated with the process of deformation of the frame of the system under the influence of forces resulting from the work of tripod drives. In the next step, an attempt was made to determine the impact of the frame support method on the obtained positioning error results. In this case, the foot spacing on which the system is supported has been changed (Figure 9). Figure 13 shows the trajectory of the movable platform in the X-Y plane with respect to the position of the support relative to the main vertical elements of the frame.

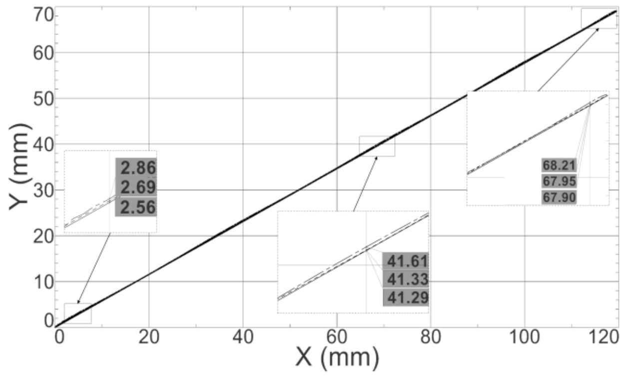

Fig. 13. The influence of the L dimension on the motion trajectory of the moveable platform

After analyzing the graphs, it can be seen that as the distance between the main support elements of the frame and the support points increases, the positioning error increases to 0.31mm at L=140mm (Table 1).

Table 1. The positioning error in reference to the L dimension

Dimension L [mm]	Maximal positioning error [mm]
35	0.05
70	0.16
140	0.31
-35	0.06

The best result can be achieved by placing the frame support points in the axis of the main support columns. Due to the method of mounting the support frame elements using a bolted connection in this place, this is not possible. In the next step, in order to fit the model to the real object, an attempt was made to map the screw connection in the frame area. This involved the need to rebuild the model prepared for motion simulation. It was also necessary to replace the frame model consisting of one body with a model composed of many bodies joined together by bolted connections (Figure 14). It was also necessary to determine separately forms and frequencies of natural vibrations in relation to the columns and platforms of the support frame of the system (Figure 15).

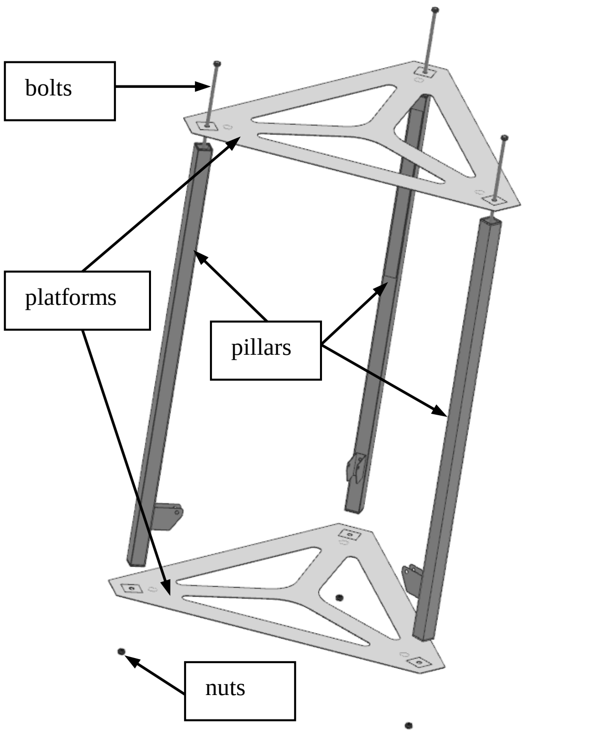

Fig. 14. The system model including bolted connection

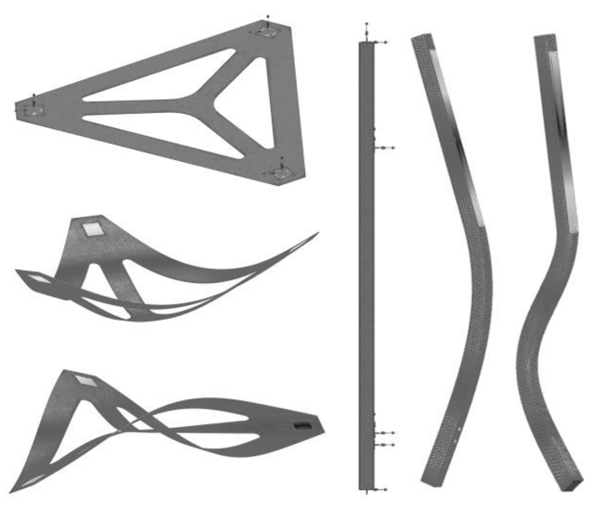
Fig. 15. The form of the frequencies of natural vibrations in relation to the pillar and platform of the frame

In the next step of the work, the cycle of the numerical simulations in relation to the modified virtual model, taking into account the screw joint between pillars and platforms of the frame was performed.

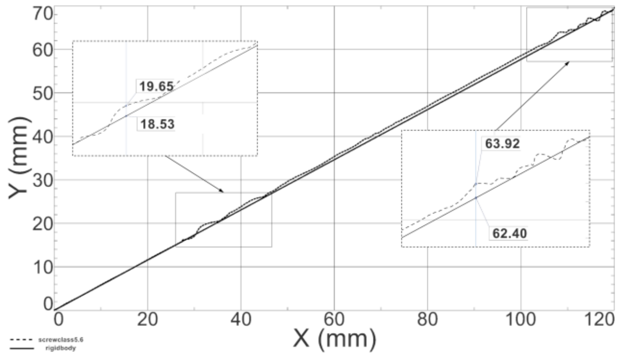

Fig. 16. The comparison of the characteristics of the movable platform (screw class 5.6)

In the analyzed model was adopted the preload forces in the bolts depending on their class. In Figure 16 the motion trajectories of the movable platform is presented, where bolts of the 5.6 screw class were used.

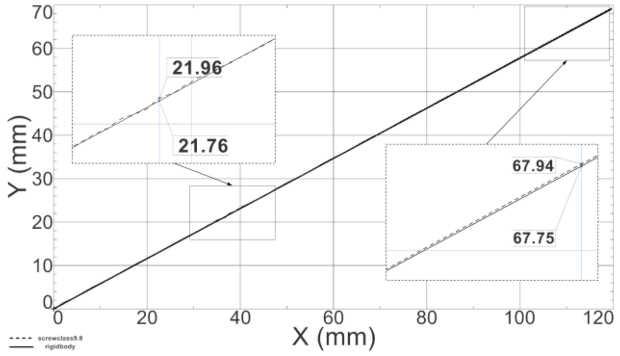

Fig. 17. The comparison of the characteristics of the movable platform (screw class 9.8)

In Figure 17 the motion trajectories of the movable platform is presented, where bolts of the 9.8 screw class were used.

Table 2. The positioning error in reference to the screw class

Screw class	Maximal positioning error [mm]
5.6	1.52
6.8	0.94
8.8	0.55
9.8	0.2

The results of the tests carried out in relation to determining the positioning error of the movable platform depending on the adopted bolt class are presented in Table 2. Analyzing the results obtained, it can be seen that as the screw class increases, the positioning error of the movable platform decreases. This is due to the occurrence of greater forces corresponding to individual elements (pillars and platforms) of the tripod support system in the form of the frame.

4. CONCLUSIONS

The work presents a motion simulation of a technical system in which one of the elements of the system (deciding on the correct operation of the movable element) is not completely rigid. Based on the conducted motion analyses, the positioning error of the movable platform was determined related to the geometrical and material properties of the flexible body element. As a result, the geometrical form of the support frame of the system has to be modified (L dimension and screw class) to the form in which an acceptable positioning error could be obtained.

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