SIMULATION ANALYSIS OF STATIC AND DYNAMIC PROPERTIES OF A PARALLEL KINEMATIC MACHINE

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Summary: In this paper, selected simulation results are shown for a construction system of a parallel kinematic machine. They concern the determining of platform traveling while it is being loaded at a given location and while performing a preset movement trajectory. The analyses were conducted with the use of Finite Elements Method (FEM) and Multibody Simulation (MBS). The verification of obtained results was performed experimentally.

Keywords: model, simulation, parallel kinematic, FEM,

1. Introduction

Designing modern machines is a complex process, demanding continuous changes towards finding an optimal solution that would meet certain criteria. The simulation method is a highly effective instrument in the analysis of this type of objects. It enables detection and property analysis of machines through conducting numerical experiments on their models, without the necessity to build prototypes [1].

The development of simulation systems is strictly related to an increasing availability of computer hardware and software, as well as with their constantly improving capabilities. Contemporary systems of that type are characterized boast more developed forms of visualization and animation [2].

One of the fields of engineering activity, in which advanced simulation techniques are used (integrated CAD/FEM/MBS systems), are design-construction processes of machine tools employing HSC technology (*High Speed Cutting*). Unconventional solutions concerning their kinematics, based upon closed kinematic chains (so-called parallel structures), are called hexapods. Compared to traditional machines (with serial kinematics), they are characterized by much higher dynamics of movement due to the reduction of transported masses [3].

In the course of this paper, results of selected simulations of construction system of a parallel kinematic machine are presented. The machine was built at the Institute of Machine Technology and Automation at Wroclaw Technical University [4]. The analyses were conducted in the IDEAS ® environment for the FEM method and in ADAMS/FLEX® environment for Multibody Simulation method (MBS) [5],[8]. The verification of obtained results was performed experimentally.

2. Structure of a numerical machine model in the analysis using finite elements method

As mentioned in the introduction, the subject of performed analyses is a hexapod-type machine, shown in Fig. 1. Its geometric-motion structure consists of two platforms stationary and movable), connected with each other by six elements [4]. Three of those elements are active elements, whereas the remaining three ensure the permanency of orientation for the working (movable) platform in relation to the stationary platform (it always moves parallel to the plane of the base). It was achieved by the application of appropriate knuckle joints (flat and crossed). Three servodrive units with turning screws were used to move that platform. The drive is fed by Ecodrive 3 engines (by INDRAMAT) with SERCOS communication interface. Controlling their work is based on a PC computer using Soft-Control technology [4]. It is worth underlining that the designing and selection of that type of units occurs according to the criterion of movement precision [6]. In case of this machine, the statement refers the precision of movement along a hypothetical tool path, mounted on the mobile platform.

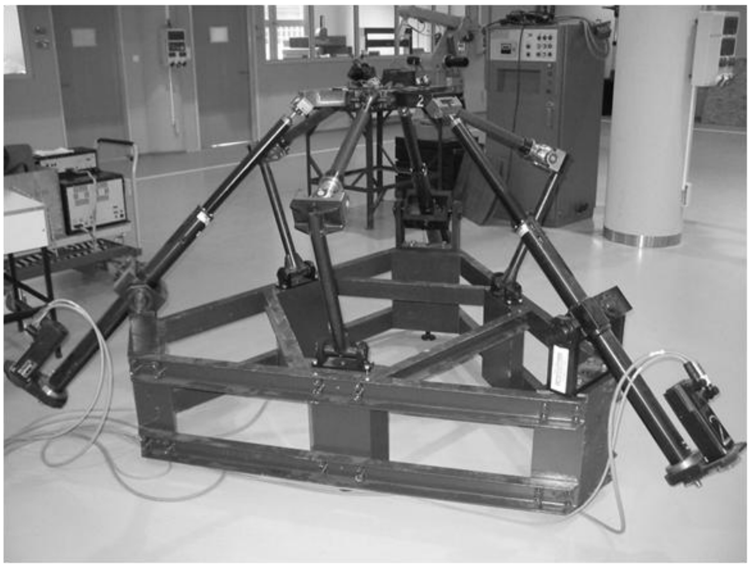


Fig. 1. View of the parallel structure unit constructed at ITMiA [4]

Fig. 2 shows a discrete model of the drive system of the analyzed machine for Finite Elements Methods [7]. Working platform was modeled with SOLID elements, whereas active and passive modules were modeled using beam elements. Kinematic couples existing in this system were modeled in such way that the number of degrees of freedom in the couples is the same as in kinematic couples of the real object. The active arm was modeled in such way that the system was simplified to two cooperating elements interconnected using SPRING elements with 320 [N/μm] rigidness. Performed analyses concerned the behavior of the system, particularly the working platform subject to the load of 650N.

Fig. 2. Numerical machine model with marked active and passive arms, together with a working platform.

The load was applied to the working platform and it worked towards the passive arm in the plane that was parallel to the working platform (Fig. 3). The research was conducted in a specific positioning of the working platform of the machine. It was adjusted in such way that all arms formed a symmetrical system. Simultaneously, its location was set at the height of 210 mm above the location in which the upper parts of passive arms are in the same plane as the platform [7].

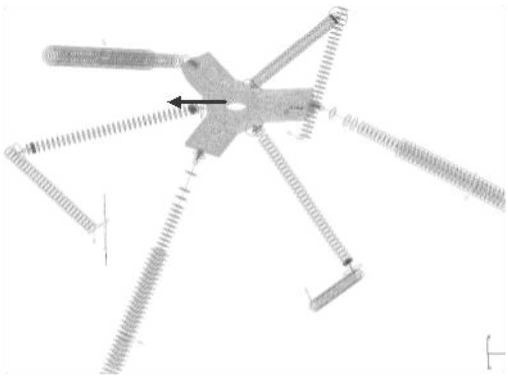


Fig. 3. Discrete model with the direction of force given

Fig. 4 presents dislocation contours within the axis of the force in the direction of the passive arm. Maximum dislocations occur in the upper platform whereas minimum ones in lower parts of passive elements. The dislocation of the working platform in the direction perpendicular to the base is visible in Fig. 5. The contours show a quite specific arrangement of mounting which has an influence on complex dislocation propagation. In the following simulation, shown in Fig. 6, the first frequency of the system was calculated and its form was drawn. A symmetrical setting of the working area in relation to active and passive arms had an influence on the character of own vibrations shown in Fig. 5 (system deformation with a visible turn of the working platform). The obtained value of frequency was 5.2Hz.

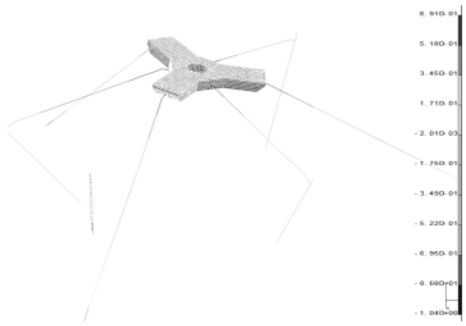


Fig. 4. Chart of dislocations [in mm] (in the force axis) of the machine obtained with the load of 650N

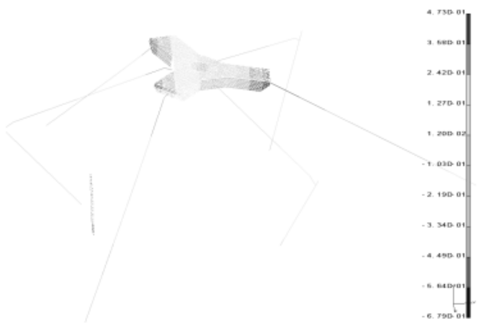


Fig. 5. Chart of dislocations [in mm] (perpendicular to the force axis) of the machine obtained with the load of 650N

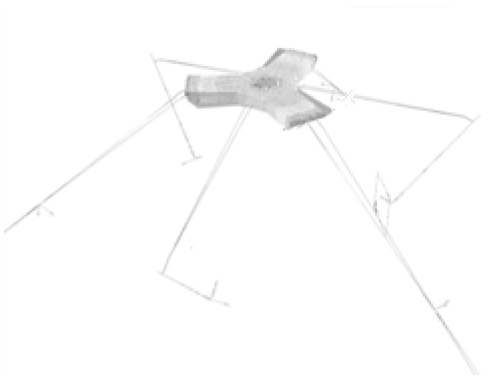


Fig. 6. The first form of own vibrations of the machine (lateral view), frequency value 5,2Hz

3. Experimental examination verifying calculations using finite elements method (FEM)

The experimental examination consisted of two stages. In the first, the system was gradually loaded up to the maximum value of 650N, with a simultaneous measurement of working platform dislocation in two directions parallel and one perpendicular to the force. In Fig. 7, a point chart of working platform dislocations is presented (measured in the direction of the force) loaded with the force with value up to the maximum value of 650N. An analogous chart was created for measurement in the direction perpendicular to the force (Fig. 8). The character of both obtained graphs unambiguously indicates a linear behavior of the system while being subject to force. In the second part of the research, the own frequency of the system was specified. The measurement was performed using a vibration analyzer recording changes in the speed of the platform (using two sensors placed on the platform). The platform was subject to driven force of 100N. On the basis of the obtained chart (Fig. 9), the frequency of own vibrations equal to 6.25HZ [7] was calculated.

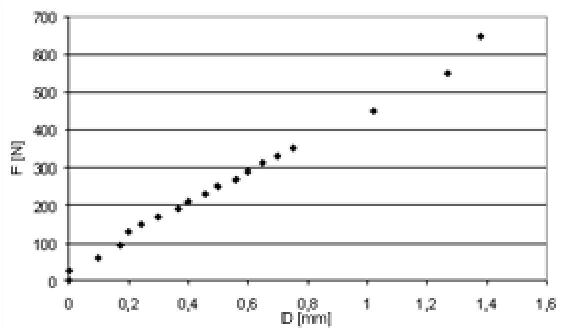


Fig. 7. Working platform dislocation chart for a system load towards the passive arm (measured in the direction of the force)

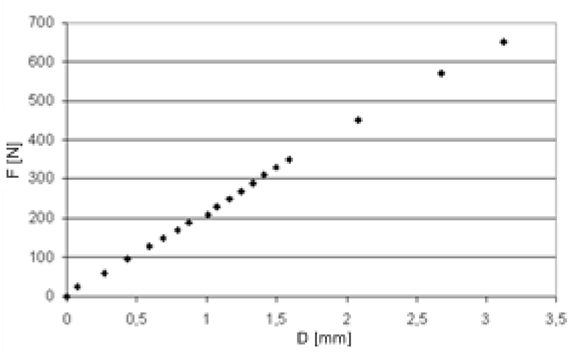


Fig. 8. Working platform dislocation chart for a system load towards the passive arm (measured perpendicularly to the force)

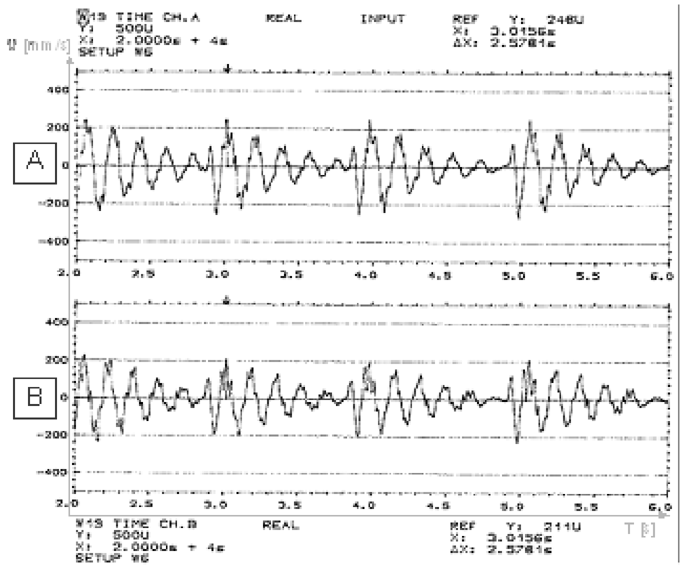


Fig. 9. Changes in platform speed in response to the driven force of 100N recorded by sensors A and B placed on the working platform

4. Construction of a numerical model for multibody simulation (mbs)

On the basis of construction documentation of the machine, another numerical model of the machine was built, this time for Multibody Simulation. The model, shown in Fig. 10, was used for conducting simulation analyses using MBS method in ADAMS® environment. They aimed at examining the behavior of the system while performing a working movement, and its stability in particular [7].

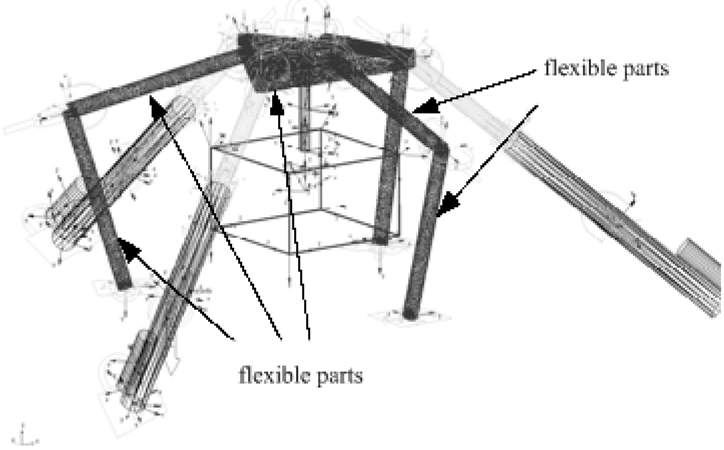


Fig. 10. A computational MBS model of a machine drive system with marked flexible parts

An MBS computational model used for kinematic analyses of the examined structure contains both rigid and flexible parts (Fig. 10). The application of the first ones is compliant with the premises of the classic MBS method [5]. They were used to model active components (arms) in the system. The other type of elements served to model passive elements (arms) and the working platform. Those elements (in the form of four-node SOLID-type spatial elements) were generated using FLEX module from ADAMS system. Kinematic couples existing in the analyzed system were modeled in such way that they would parallel the couples in a real system.

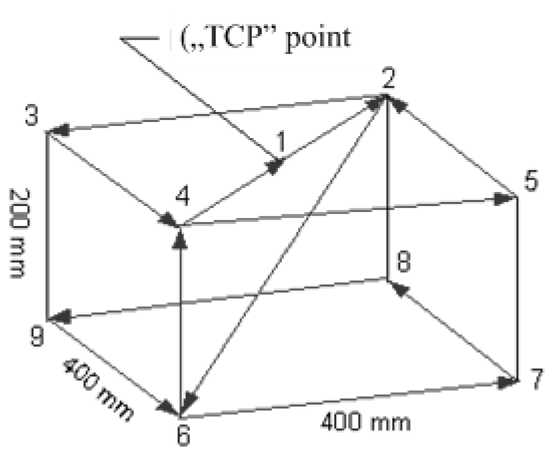


Fig. 11. Preset movement trajectory of a hypothetical tool („TCP" point)

Fig. 11 presents an assumed movement trajectory, along which the "TCP" (ang. *Tool Center Point*) moved. It was the center of the coordinate system, related to the hypothetical tool. The trajectory includes its movement from point 1 through points 2,3,4,5,2,6,7,8,9,6,4 and its return to point 1. It is limited by a rectangular prism with the following dimensions: 400x400x200 mm, which corresponds to the assumed size of the working area. It was preset at the stage of preparing preliminary construction premises for the examined machine [4].

In order to perform the assumed working platform movement (trajectory from Fig. 11), specific component values of feed movement for withdrawable kinematic couples (active arms) of the model. Their courses are shown in Fig. 12. It was implied that the speed of the movement will have the value of 0.02 m/s [7].

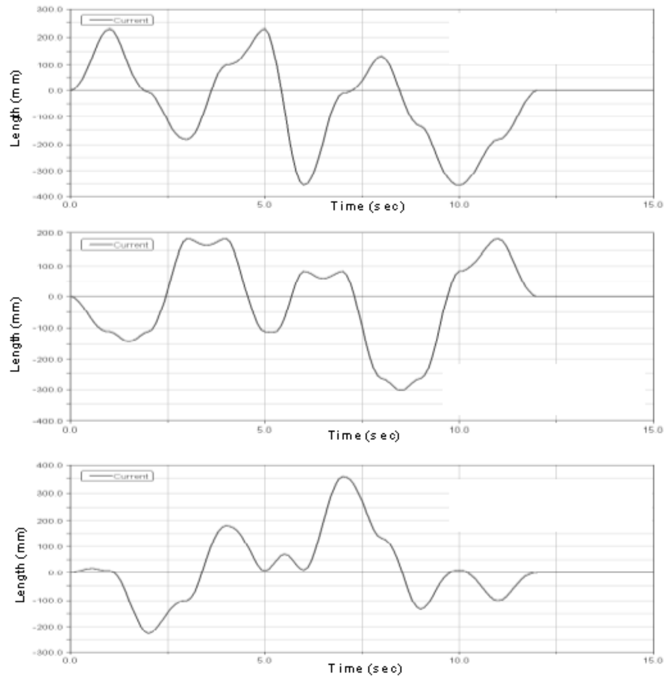
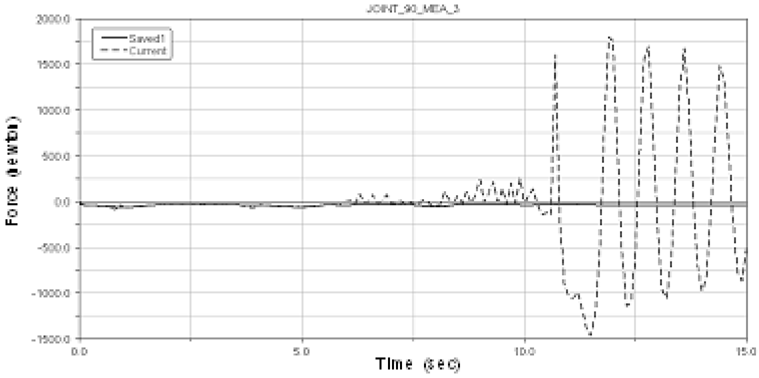


Fig. 12. Courses of feed movement components for with drawable kinematic couples

5. Selected results of the mbs analysis and experimental examinations

Analyses conducted in ADAMS/FLEX environment for Multibody Simulation (MBS) proved that while traveling through corners of the working area, there is a loss of stability.. Charts presented in Fig. 13 show how significant changes in forces (for one of the joints of the passive arm) and speed (for the platform) appear in the system. It concerns point 6 of the preset trajectory in particular (after approximately 11 seconds of movement). It is worth noticing, that simulation with the use of the classic MBS model (without flexible elements), do not indicate the existence of such phenomenon (curve Saved1 in Fig. 13a concerns the course of signal for the model with rigid elements) [7].

a.



b.

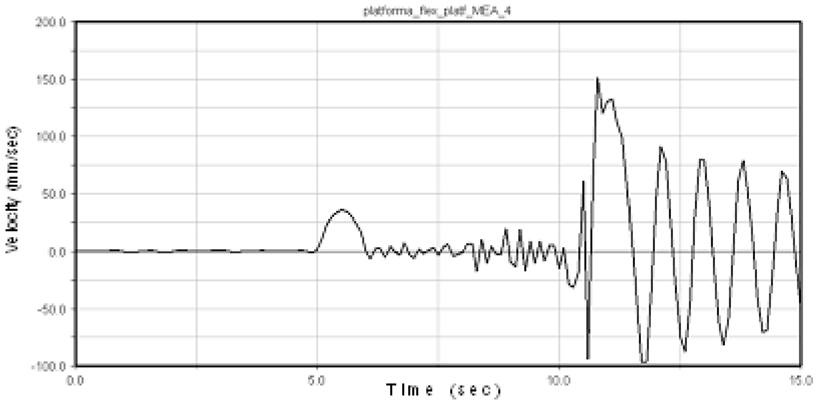
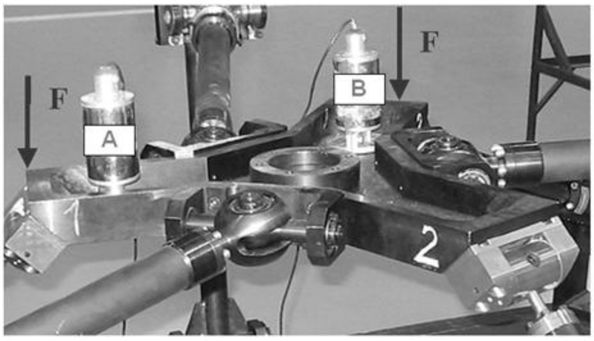


Fig. 13. Courses of changes in forces and speeds in the system (in the direction of the Z-axis) during working platform movement along a given trajectory with the speed of 0,02m/s

The emergence of problems with the realization of the preset movement trajectory was also confirmed by experimental examination. It consisted in recording changes in working platform speed in the direction of the Z-axis (perpendicular to the base of the machine). Two inductive acceleration sensors placed on the platform were used to record the changes (Fig. 14a).

a.



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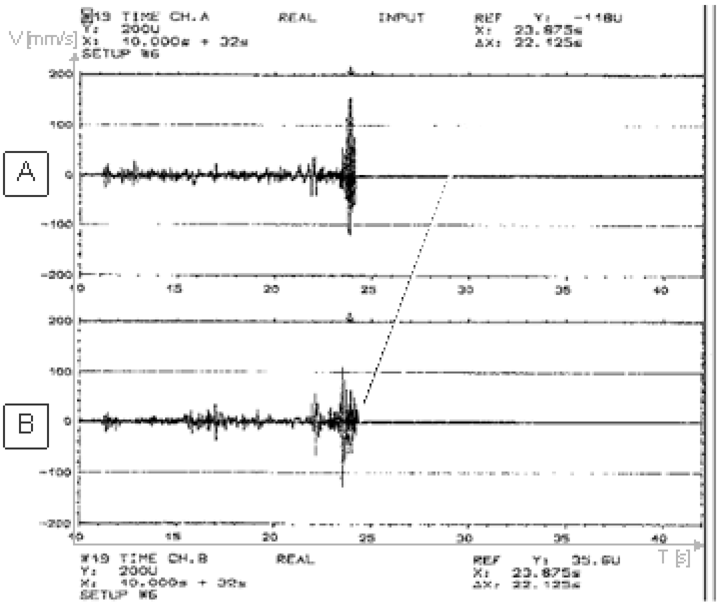

Fig. 14. Location pattern of measuring sensors on the working platform and recorded changes in platform speed for traveling at the speed of 0,02 m/s

Fig. 14b shows registered changes in working platform movement, obtained during a hypothetical tool movement along a given trajectory at the speed of 0,02m/s. As can be seen, also in the area of point 6, there occurs a large distortion of that movement. It was necessary to stop the examined movement.

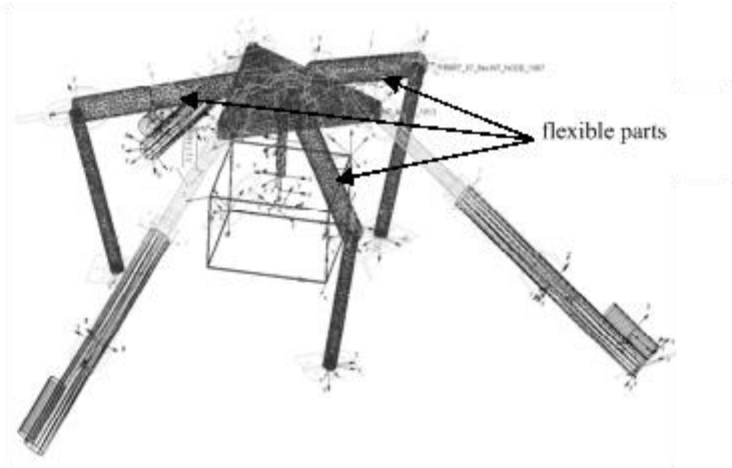

Fig. 15. Computational model of the machine drive system with flexible parts (elements of passive arms with increased rigidness)

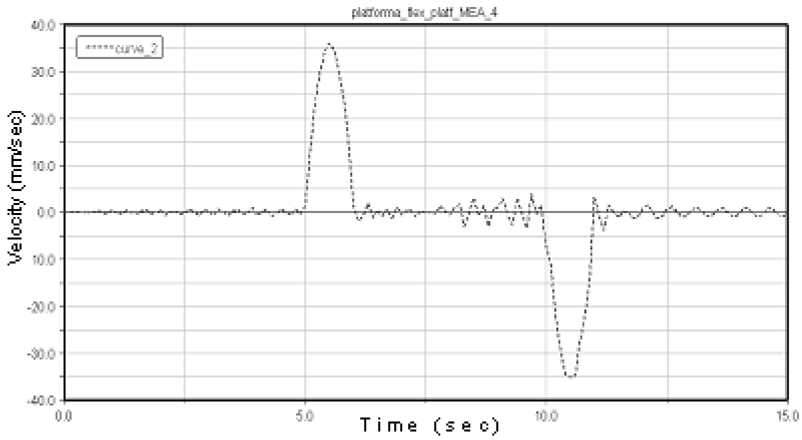

Fig. 16. Changes in speed (in the direction of the Z-axis), set for working platform during movement along a given trajectory at the speed of 0,02m/s (with changed values of rigidness of passive elements)

Based upon the results of conducted analyses, changes in machine construction were proposed, the rigidness of upper elements of passive arms was increased (Fig. 15) [7]. Their aim was to eliminate unfavorable phenomena appearing during the performance of movement along a given trajectory. Calculations done using FEM method, as well as MBS, proved that passive arms have a large significance for the rigidness of the system and passive arms affect its stability. The influence of introduced changes in the construction of passive arms, regarding their rigidness, is illustrated in Fig. 16.

4. Final conclusions

Unconventional solutions in the field of constructing modern manufacturing machines (hexapods) are based on closed kinematic chains. The new quality of phenomena and their scale, together with a constantly increasing area of application for such machines, force the necessity of using advanced computer technologies at the design stage. Integrated simulation systems CAD/FEM/MBS play a very special role here. The results of simulations and experiments contained in this paper confirmed the existence of unfavorable phenomena while performing movement by the working platform of the machine with parallel kinematics. To avoid such irregularities, changes in construction were made, which consisted in the increase of the rigidness of passive elements.

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