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KINEMATIC AND DYNAMIC SIMULATION OF A 3DOF PARALLEL ROBOT

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Abstract: *This paper presents a kinematic and dynamic study of a 3DOF parallel structure of type 1PRRR+2PRPaR, with one decoupled motion and two coupled motions, composed by a mobile platform connected to the fixed base by three kinematic chains. A numerical simulation of the kinematic and dynamic behaviour of this parallel robot in the assumption of rigid links is presented comparatively with an equivalent structure with two flexible links, modelled with ADAMS AutoFlex module. The results show a significant influence of the natural flexibility of links on the effector speed and acceleration, along with large variation of the active forces in the three linear actuators. Thus, the results on the robot behaviour in the flexible links' assumption are useful input data in and control systems.*

Key words: *parallel robot, kinematic, dynamic, simulation, ADAMS software, ADAMS AutoFlex module.*

1. Introduction

In the last years, the parallel robots have been more and more studied and developed from theoretical view point and also for practical applications. The advantages offered by parallel manipulators (PMs) are high stiffness, excellent load-to-weight ratio, positioning accuracy and good dynamic behaviour [8]. The parallel robots are mechanisms with closed kinematic chains, composed by a mobile platform (the end-effector) with n degrees of freedom, connected to the fixed base by two or more kinematic chains called limbs or legs. A simple or a complex kinematic chain can be associated with each limb [3].

A kinematic modelling of a 3DOF parallel robot is detailed in [6] and an analytical model following by numerical simulation is presented in [1].

Regarding the dynamic model of parallel robots, different methods can be applied. Yen and Lai [7] obtained the dynamic equations of a 3DOF translational parallel manipulator using the Lagrange-D'Alembert formulation.

Euler-Lagrange method applied to obtain the dynamic model of a parallel kinematic machine is presented in [4]. Also, a new approach to multi-objective dynamic trajectory planning of parallel kinematic machines (PKM) under task, workspace and manipulator constraints is presented here.

The inverse dynamic model of a 5-DOF hybrid parallel robot is detailed in [2]. The virtual work method based on the dynamically equivalent lumped masses is used.

This paper presents the kinematic and dynamic simulation of a 3DOF parallel

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robot of type 1PRRR+2PPPaR based on analytical models presented in [1] and [5] and simplified models with rigid links developed in ADAMS software. In the second part of the paper, the influence of links' flexibility on the robot kinematic and dynamic behaviour is also approached considering a fifth degree polynomial low of movement in motor joints. The comparative numerical simulations on a representative trajectories of this parallel robot in both rigid vs. flexible links assumptions are developed to draw useful recommendations for researchers and practitioners from the robotic field.

2. Description of the 1PRRR+2PRPaR Parallel Robot

The parallel robot of type 1PRRR+ 2PRPaR (1Prismatic, Revolute, Revolute, Revolute + 2Prismatic, Revolute, Parallelogram, Revolute) has 3 degrees of freedom (DOF) with one decoupled motion along X axis and two coupled motions [3], (Figure 1).

This parallel robot is composed by a mobile platform 7 connected to the base 0 by three kinematic chains (Figure 1):

- one simple open kinematic chain with one active prismatic joint and three passive revolute joints;
- two complex kinematic chains of parallelogram type with one active prismatic joint and six passive revolute joints.

3. Kinematic Simulation

Starting from the kinematical model developed in Maple and presented in [1], a numerical simulation of this model is

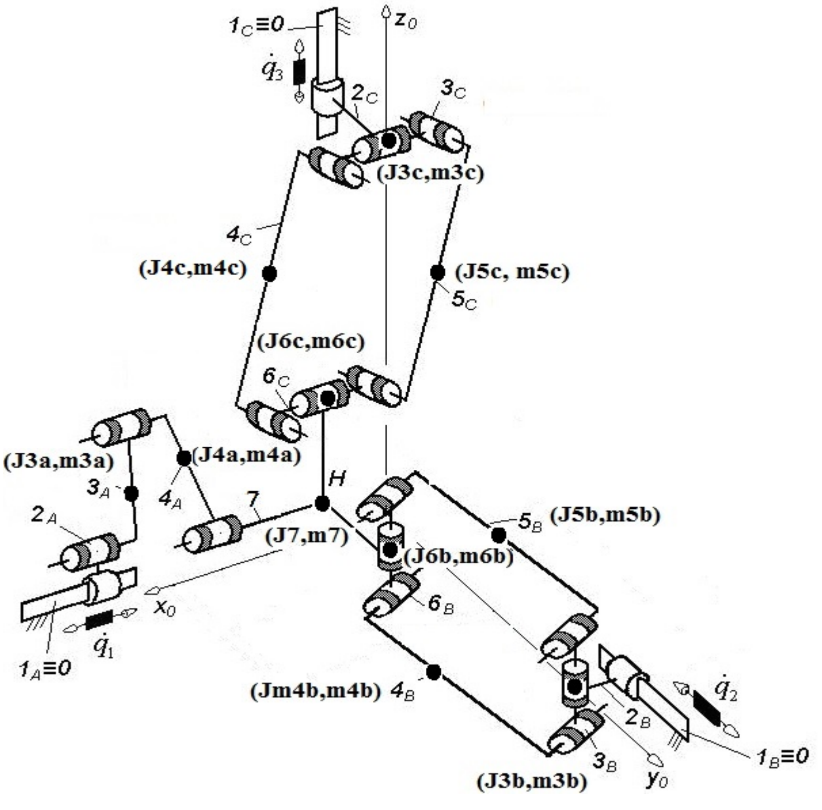
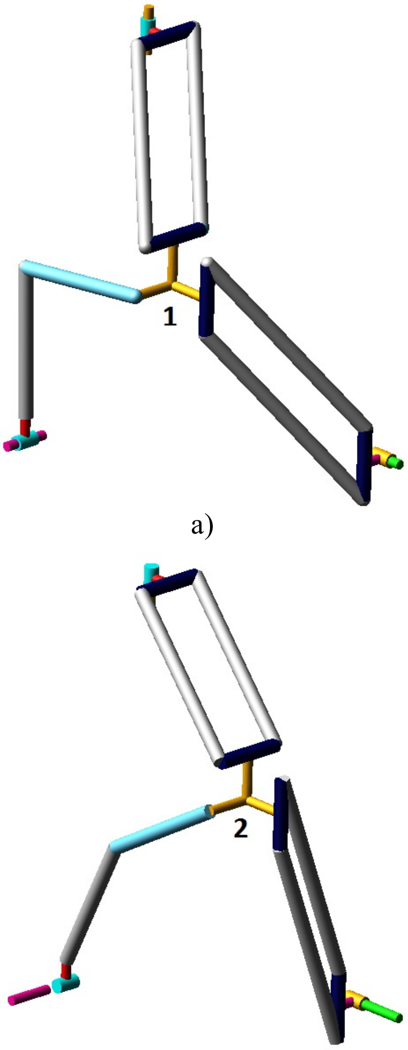


Fig. 1. *Dynamic scheme of the parallel robot of 1PRRR+2PRPaR type*

carried out considering a linear trajectory in the Cartesian space between the point 1 (0.5 m, 0.6 m, 0.7 m), Figure 2a, and point 2 (0.3 m, 0.8 m, 0.9 m), Figure 2b, using a fifth degree polynomial movement low (Figure 3) with the end-effector maximum acceleration reaching 1 m/s^2 while the linear motor 3 develops a maximum acceleration of 5 m/s^2 (Figure 4c).

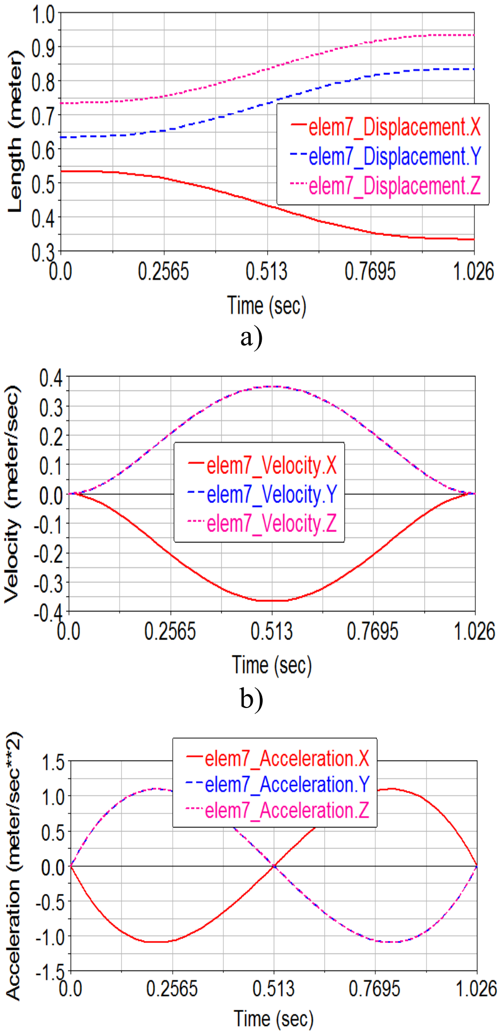


a)

b)

Fig. 2. *ADAMS model of the parallel robot of 1PRRR+2PRPaR type in rigid links hypothesis represented at the beginning (a) and at the end (b) of the trajectory*

Starting from desired motion of the end-effector (link 7), Figure 3, the needed motions of the drive motors are determined, Figure 4.



a)

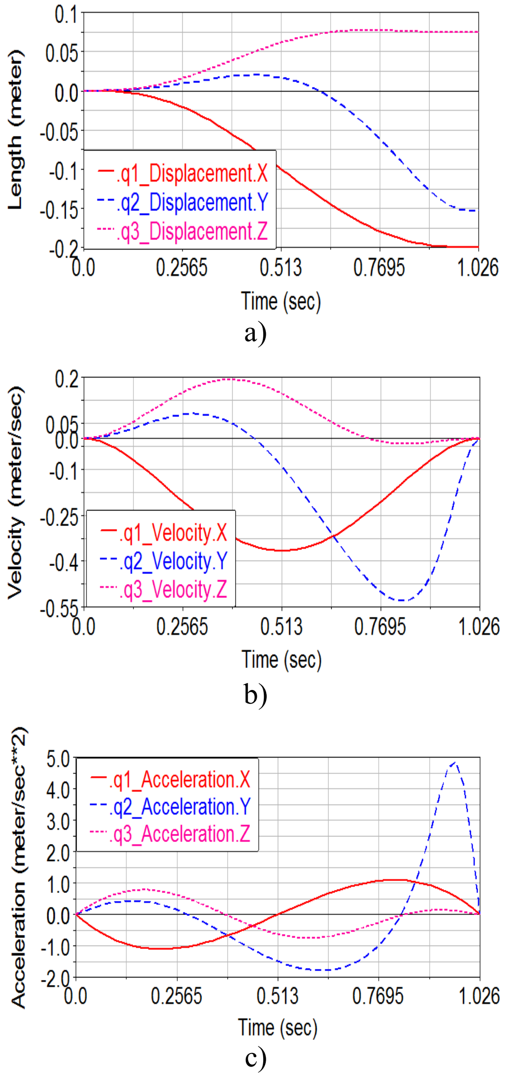
b)

c)

Fig. 3. *The imposed end-effector motion: displacements (a), velocities (b), and accelerations (c)*

4. Dynamical Simulation in the Rigid vs. Flexible Links Hypothesis

Based on the dynamical model developed by applying the Lagrange with multipliers methods in rigid links hypothesis [5], a numerical simulation has obtained in Maple software considering the input values form Table 1.



a)

b)

c)

Fig. 4. *The motion needed in the linear motor drives : displacements (a), velocities (b), and accelerations (c)*

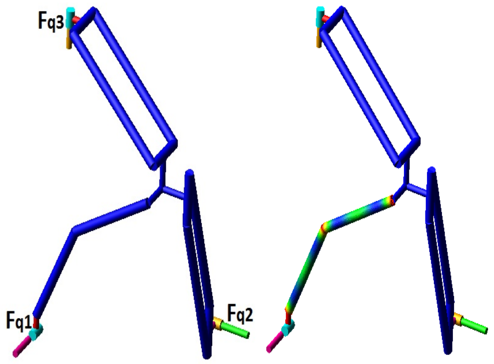
Also, numerical simulations are done in the Adams software in both rigid and flexible link assumptions. In this study, the natural flexibility of the links 3a and 4a (Figure 1) was only considered.

Starting from the Adams model obtained in rigid links hypothesis (Figure 5a), a new model with flexible links was derived used ADAMS AutoFlex module. In this way, the influence of flexible links 3a and 4a on the dynamic behaviour of this parallel robot (Figure 5b) was obtained considering only the natural frequency smaller then 2500Hz (Figure 6).

Table 1

Geometric and mass parameters

$l_{3a} = l_{4a}$	0.63 [m]
$l_{3b} = l_{3c}$	0.15 [m]
$l_{4b} = l_{4c}$	0.95[m]
$l_{7a} = l_{7b} = l_{7c}$	0.2 [m]
$m_{3a} = m_{4a}$	9.68 [kg]
$m_{3b} = m_{3c}$	2.32 [kg]
$m_{4b} = m_{5b}$	7.35 [kg]
$m_{4c} = m_{5c}$	7.35 [kg]
$m_{6b} = m_{6c}$	2.32 [kg]

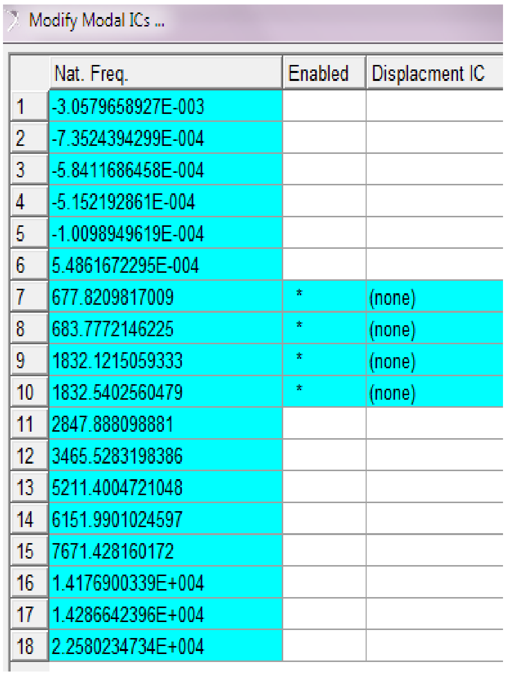


a) b)

Fig. 5. *The Adams models of robot with: rigid links (a), and flexible links (b)*

Regarding the dynamic behavior of the parallel robot in rigid links hypothesis, the Figure 7 shows that the maximum driving force is achieved in the X linear motor (Fq1) with decoupled motion (more than 700 N).

The parallel robot with flexible links encounters variations of the driving forces with large amplitude and high frequencies in the first part of the trajectory (Figure 7). The maximal value of the driving forces in the flexible robot are about two times bigger than in the case of the parallel robot with rigid links.



	Nat. Freq.	Enabled	Displacment IC
1	-3.0579658927E-003		
2	-7.3524394299E-004		
3	-5.8411686458E-004		
4	-5.152192861E-004		
5	-1.0098949619E-004		
6	5.4861672295E-004		
7	677.8209817009	*	(none)
8	683.7772146225	*	(none)
9	1832.1215059333	*	(none)
10	1832.5402560479	*	(none)
11	2847.888098881		
12	3465.5283198386		
13	5211.4004721048		
14	6151.9901024597		
15	7671.428160172		
16	1.4176900339E+004		
17	1.4286642396E+004		
18	2.2580234734E+004		

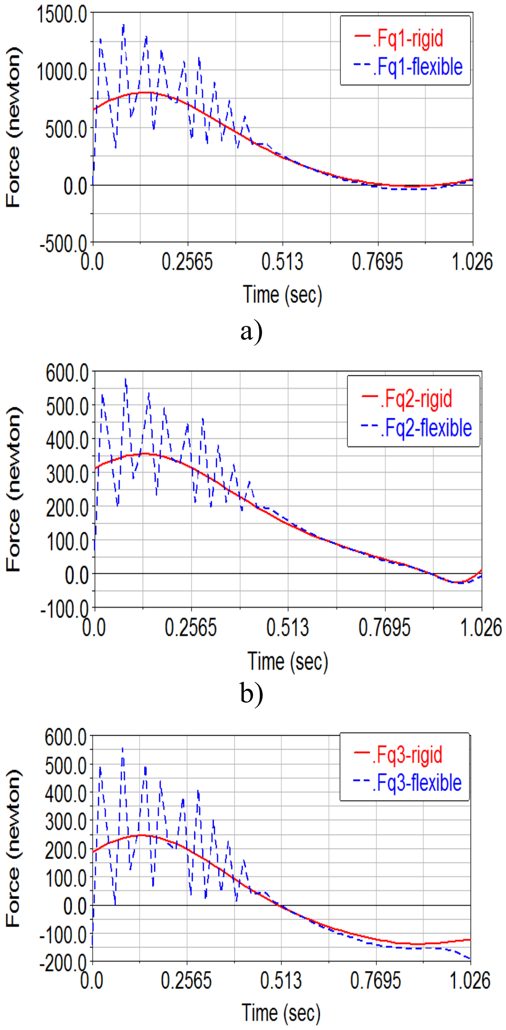
Fig. 6. *Natural frequency of the parallel robot of 1PRRR+2PRPaR type in the flexible links hypothesis*

6. Conclusion

A kinematic and dynamic simulation of maximally regular parallel robots [3], with application to the coupled topology, has been presented in this paper starting from the analytical models detailed in [1] and [5].

The numerical kinematic simulations point out the kinematic behavior of the robot: decoupled motion on the X axis and coupled motions for the other two axis (Y and Z). Also, higher accelerations in the motor drives are needed (up to 5 time bigger in the Y linear motor) to generate a desired end-effector acceleration (e.g. 1 m/s^2).

Dynamic simulations in the rigid links' hypothesis allow to obtain the driving forces developed by the linear motors, where a maximum force of 700 N is developed by the X motor drive.



a)

b)

c)

Fig. 7. *The variation of driving force Fq1 (a), Fq2 (b) and Fq3 (c) in rigid (red-continuous line) and flexible (blue-dash line) hypothesis*

When the flexible links assumption is taken into consideration for one arm (arm *a* with the most flexible links, Figure 1) and its natural frequencies up to 2500 Hz, the dynamic results show a major influence of the links' flexibility on the driving force variations.

In conclusion, kinematic and dynamic simulations for a parallel robot using ADAMS software are presented in this paper, including the study of the influence of the link flexibility.

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