

**Modern Technologies in
Industrial Engineering**



ModTech 2013[®]

Edited by
Constantin Carausu, Viorel Cohal, Ioan Doroftei,
Andrzej Wrobel and Dumitru Nedelcu

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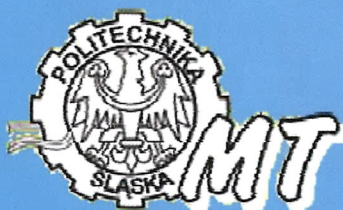


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Preface

The main objectives of ModTech International Conference - Modern Technologies in Industrial Engineering are to bring together representatives of technology manufacturers, of various state institutions, universities, industry, professional associations, to debate and exchange experiences on important Conference topics. Another main objective of ModTech International Conference consists of providing a good networking opportunity to all these groups.

The ModTech2013 International Conference became a major conference to exchange the new ideas of science and technology among Europe, Asia and USA researchers and scientists and provide a forum to present their new results focused on the main topics of the conference. It is held in Sinaia in Romania from June 27 to 29 hosted by Professional Association in Modern Manufacturing Technologies, ModTech, as main organizer, Silesian University of Technology, Gliwice, Poland and Maritime University of Constanta, Romania as co-organizers.

On the first edition of the ModTech2013 International Conference 414 abstracts were received, 373 of which were accepted. 110 researchers from 18 countries participated, namely from: Japan, USA, Germany, South Korea, Russia, Italy, Romania, Poland, Portugal, Spain, France, Slovakia, Republic of Moldova, Croatia, Serbia, Turkey, Greece and Tunisia.

In addition to the authors that were present at the conference, researchers from Switzerland, India, Slovenia, Uzbekistan, Belgium, Finland, Mexico and Vietnam also send papers. In all, authors from 26 various countries worldwide.

As concerns the representatives of the Romanian universities, business entities /research institutes, the authors come from 17 prestigious universities and from 10 business entities or research institutes. The foreign authors represent 34 universities worldwide and 13 research institutes.

The main publication of ModTech2013 International Conference were as follow: International Journal of Materials & Product Technology, Indian Journal of Engineering & Materials Sciences, Materials Science-Poland, International Journal of Modern Manufacturing Technologies and Advanced Materials Research-AMR" by Trans Tech Publications Inc. (TTP).

Dumitru Nedelcu
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DYNAMIC MODELLING OF A 3DOF MEDICAL PARALLEL ROBOT WITH ONE DECOUPLED MOTION

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Keywords: parallel robots, medical robots, dynamic modeling, Lagrange multipliers method, numerical simulations.

Abstract

The paper presents the dynamic modeling of a 3DOF parallel robot of 1PRRR+2PRPaR type using the Lagrange multipliers method in the rigid link assumption. Numerical simulations of the analytical dynamic model, developed using Maple software, on representative trajectories are carried out and these results are finally validated through numerical simulations in the MBS ADAMS software. Final conclusions are drawn, useful for researchers and practitioners in the robotic field.

Introduction

The parallel robots are known as mechanism with high accuracy due to the non cumulative joint errors. The advantages offered by parallel manipulators (PMs) are: excellent load-to-weight ratio, high stiffness and positioning accuracy and good dynamic behavior [1].

The parallel robots are mechanisms with closed kinematic chains, composed by a mobile platform connected to the fixed base by minimum two kinematic chains (simple or complex) [2].

Different methods can be applied for obtaining the dynamical model of the parallel robots. Using the Lagrange-D'Alembert formulation, Yen and Lai [3] obtained the dynamic equations of a 3DOF translational parallel manipulator.

Lu and Xu [4] developed a dynamic model for a translational parallel robot, deriving the dynamic analytical model using the simplified dynamic equations obtained via the virtual work principle and validated on a virtual prototype with the ADAMS software.

Khoukhi et al. [5] applied the method Euler-Lagrange to obtain the dynamic model for a parallel kinematic machine. A new approach to multi-objective dynamic trajectory planning of parallel kinematic machines (PKM) under task, workspace and manipulator constraints is also presented.

A recursive model for developing kinematics and dynamics of a 3-PRR planar parallel robot was used by Staicu [6]. The principle of virtual work is applied for solving the inverse dynamic problem.

By means of the principle of virtual work and the concept of link Jacobian matrices, Zao and Gao [7] developed the inverse dynamic model of the redundant parallel manipulator, obtaining six linear consistent equations with eight unknown quantities.

Zhang et al. [8] proposed an innovative design for a parallel manipulator with 3-DOF, including the rotations of a moving platform along X and Y axis and translation of this platform along the Z axis. Kinematic aspects are investigated and a dynamic model using a Newton-Euler approach is implemented. The global system stiffness of the parallel robot is formulated and the kinetostatic analysis is conducted. Finally, a case study was presented to demonstrate the applications of the kinematic and dynamic models and to verify the concept of the new design.

The methodology of the dynamic optimum design of a three translational degrees of freedom parallel robot (Delta robot) while considering anisotropic property is presented [9].

The paper [10] presents a dynamics identification of kinematically redundant parallel robots based on the Lagrange equations of the first kind and using the coordinate partitioning method the dynamic equations of the considered mechanism are derived analytically in a reduced symbolic form. For this parallel robot, a set of minimal dynamic parameters is automatically obtained.

The inverse dynamic model for a 5-DOF hybrid parallel robot is detailed in [11]. The virtual work method based on the dynamically equivalent lumped masses is used.

The paper [12] presents the methodology of the dynamic optimum design of a three translational degrees of freedom parallel robot (Delta) while considering anisotropic property. Taking the acceleration, velocity, and gravity components into account, the torque and power indices are adopted as the objective functions for the dynamic optimum design.

The dynamic modelling of a medical parallel robot is developed in the paper using the Lagrange multipliers method in the rigid link hypothesis. The results of numerical simulations on a given trajectory emphasize the influence of the parallel robot kinematic and dynamic properties on the driving forces. Furthermore, numerical simulations on representative trajectories of the analytical dynamic model, developed using Maple software, are fulfilled and the results are finally validated through simulations in MBS ADAMS software. Final conclusions are drawn, useful for researchers and practitioners in the robotic field.

Description of 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 (Fig. 1).

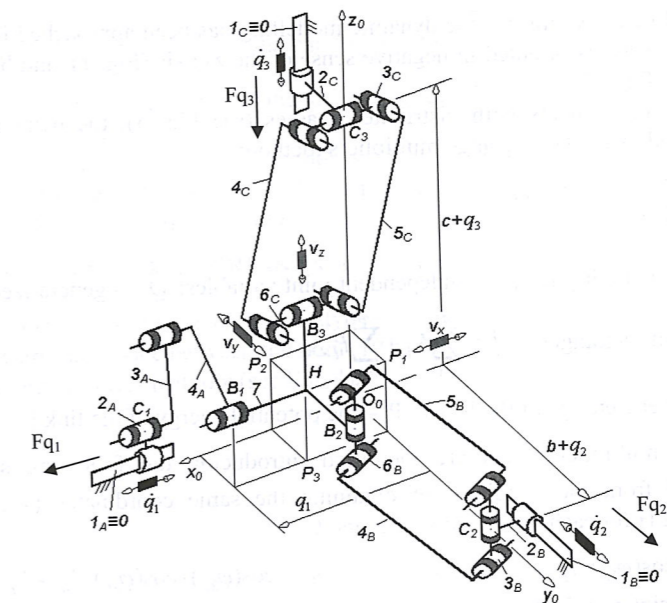


Fig. 1 Kinematic scheme of the parallel robot of 1PRRR+2PRPaR type [9].

This parallel robot is composed by a mobile platform 7 connected to the base by three kinematic chains:

- A: simple open kinematic chain with one active prismatic joint (independent joint parameter q_1) and three passive revolute joints (dependent joint parameters φ_{2a} , φ_{3a} and φ_{4a}) – see Fig. 2,b;
- B and C: complex kinematic chains of parallelogram type with one active prismatic joint (independent joint parameter q_2 and respectively q_3) and six passive revolute joints (dependent joint parameters φ_{2i} , φ_{3i} , $\varphi_{3i'}$, φ_{4i} , $\varphi_{4i'}$, and φ_{5i} – where $i = b,c$) – Fig. 2,a.

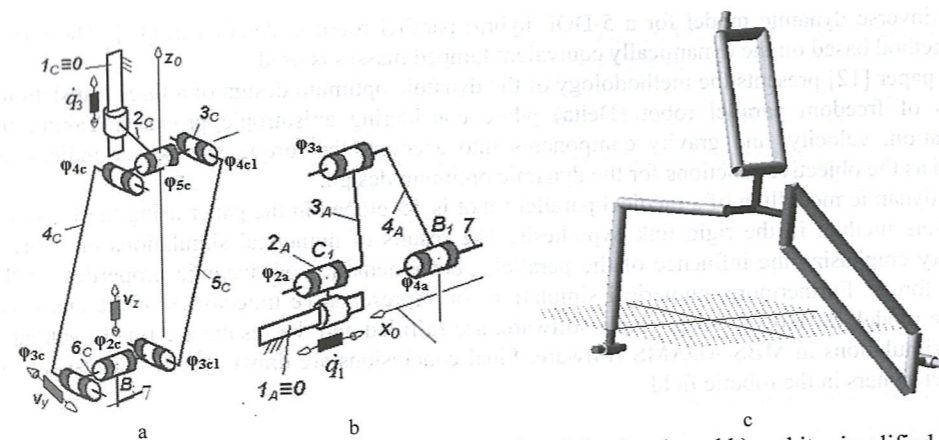


Fig. 2 Parameterization of the 1PRRR+2PRPaR parallel robot (a and b) and its simplified CAD model in ADAMS (c)

Dynamical modeling of 1PRRR+2PRPaR parallel robot in the rigid links hypothesis

Based on rigid links hypothesis, the dynamic modelling has been approached in the assumptions of: a) the gravity vector is oriented in negative sense of the z_0 axis (Fig. 1), and b) no external load on the moving platform 7.

Considering rigid elements with distributed masses (see Fig. 3), the dynamic model can be analytically derived using the Lagrange multipliers method:

$$\sum_{i=1}^k \lambda_i \frac{\partial \Gamma_i}{\partial q_j} = \frac{d}{dt} \left(\frac{\partial L}{\partial \dot{q}_j} \right) - \frac{\partial L}{\partial q_j} - \hat{Q}_j \quad (1)$$

where: λ_i - Lagrange multipliers; q_j - independent joint variables; \hat{Q}_j - generalized external forces;

$$L - \text{parallel robot Lagrangean: } L = \sum_{i=1}^n K_i + \sum_{i=1}^n P_i, \quad (2)$$

where: K_i - the kinetic energy of the link i ; P_i - the potential energy of the link i .

The Lagrange multipliers (λ_i) are identified introducing the following set of geometric equations derived from the condition of obtaining the same coordinates (x_H, y_H, z_H) of the characteristic point H for each of the arms A, B and C:

$$(\Gamma_i): \begin{cases} EC_1 = \cos(\varphi_{2a}) \cdot l_{3a} + l_{4a} \cdot \cos(\varphi_{2a} + \varphi_{3a}) - q_2 - \cos(\varphi_{2b}) \cdot \cos(\varphi_{3b}) \cdot l_{4b} + l_{7b} \\ EC_2 = \sin(\varphi_{2a}) \cdot l_{3a} + l_{4a} \cdot \sin(\varphi_{2a} + \varphi_{3a}) - q_3 - \cos(\varphi_{2c}) \cdot \cos(\varphi_{3c}) \cdot l_{4c} + l_{7c} \\ EC_3 = \sin(\varphi_{2b}) \cdot \cos(\varphi_{3b}) \cdot l_{4b} - q_1 + l_{7a} \\ EC_4 = \sin(\varphi_{3b}) \cdot l_{4b} - q_3 - \cos(\varphi_{2c}) \cdot \cos(\varphi_{3c}) \cdot l_{4c} + l_{7c} \\ EC_5 = \sin(\varphi_{3c}) \cdot l_{4c} - q_1 + l_{7a} \\ EC_6 = \sin(\varphi_{2c}) \cdot \cos(\varphi_{3c}) \cdot l_{4c} - q_2 - \cos(\varphi_{2b}) \cdot \cos(\varphi_{3b}) \cdot l_{4b} + l_{7b} \end{cases} \quad (3)$$

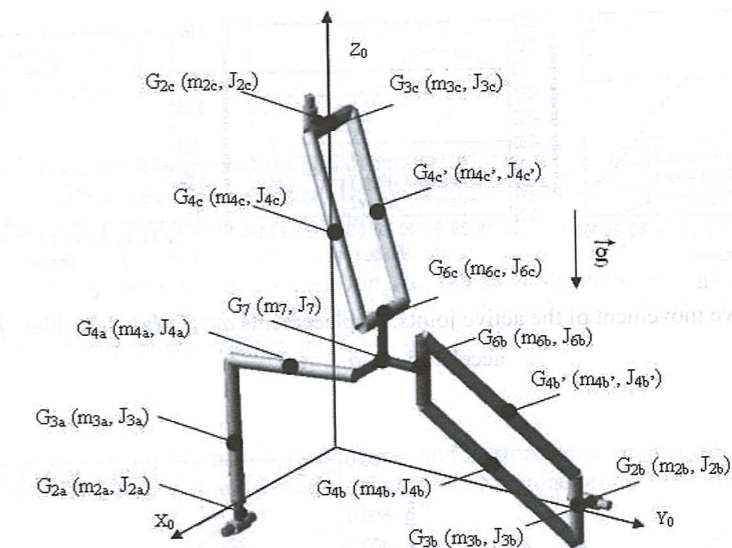


Fig.3 Dynamic scheme of the parallel robot of 1PRRR+2PRPaR type

Finally, the analytical expressions of the driving forces Fq_1, Fq_2 and Fq_3 (see Fig. 1) are obtained using Maple software.

Even the obtained analytical dynamic model is of high complexity, the Lagrange multipliers method can be usefully applied to derive the dynamical model of any 3 DOF parallel robots and can be extended to 4 and more DOF parallel robots.

Numerical simulation of 1PRRR+2PRPaR parallel robot

Numerical simulation of the dynamic analytical model is carried out considering a linear trajectory in the Cartesian space between the point 1(0.5, 0.6, 0.7) and point 2(0.3, 0.8, 0.9), using a fifth degree polynomial movement law (see Fig. 4).

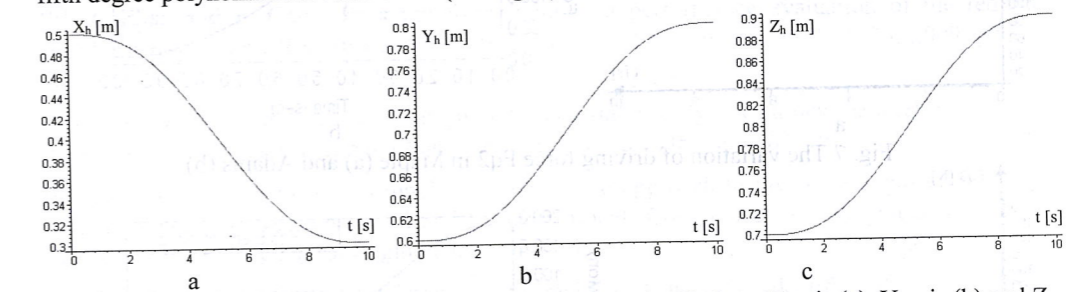


Fig. 4 Displacement of the end-effector characteristic point H along X axis (a), Y axis (b) and Z axis (c)

For these imposed movements of the characteristic point H, the relative movement (displacements, velocities and accelerations) in the three active joints were obtained and drawn in Fig. 5. The maximum velocity and acceleration on the desired end-effector trajectory are obtained in driving joint (q_2). To validate the analytical results, numerical simulations are performed in Adams for the same values of the input parameters as used in the Maple simulation; as the same driving force variations were obtained (see Fig. 6, 7 and 8), it can be conclude that the analytical model was correctly developed.

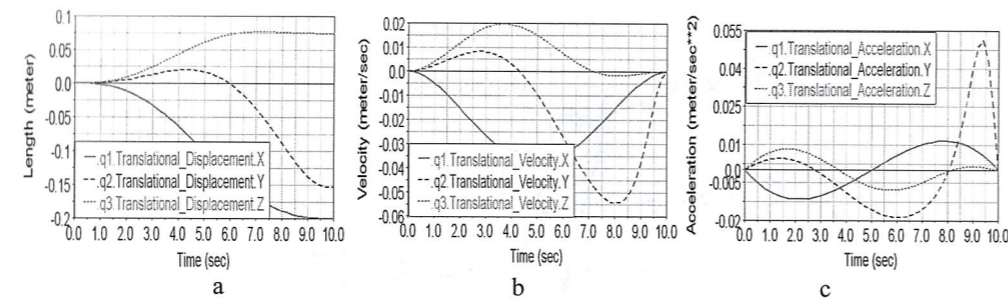


Fig. 5 The relative movement of the active joints: displacements $q_{i, i=1..3}$ (a), velocities $\dot{q}_{i, i=1..3}$ (b) and accelerations $\ddot{q}_{i, i=1..3}$ (c)

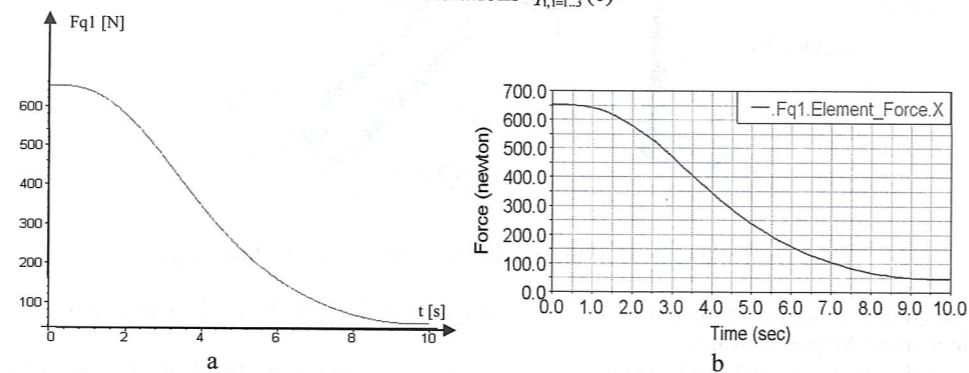


Fig. 6 The variation of driving force Fq1 in Maple (a) and Adams (b)

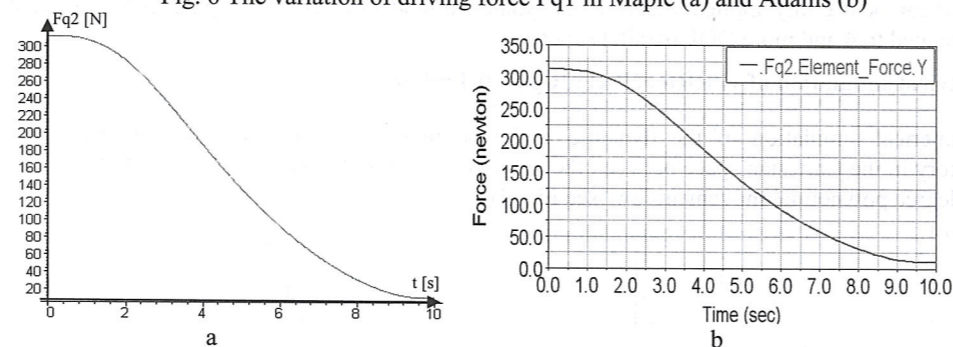


Fig. 7 The variation of driving force Fq2 in Maple (a) and Adams (b)

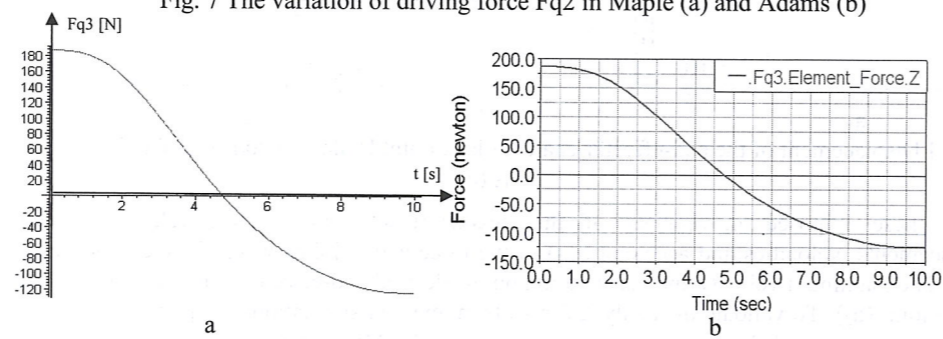


Fig. 8 The variation of driving force Fq3 in Maple (a) and Adams (b)

Fig. 6-8 highlight that the maximum driving force is achieved in the X linear motor (Fq1) with decoupled motion.

Conclusions

A dynamic modeling of maximally regular parallel robots [2], with application to the coupled topology, has been presented in this paper. The closed-form dynamic model was developed in the rigid link hypothesis using Lagrange with multipliers method. With the obtained analytical dynamic model, a control model can be added to complete the study.

The numerical simulations, performed for the obtained dynamic analytical model and a correspondent CAD model using ADAMS software, highlighted identical robot behavior and thus the closed form dynamic model was validated.

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