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The Forces of a Simple Carrier Manipulator

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Abstract: The present paper shows how to analytically determine the forces acting within a simple manipulator. Forces acting within any device or car have an important role because they are the ones that define the real movement of that device, the dynamic movement, movement that is very different from the cinematic imaginable by geometric-kinematic engineering calculations. To know the real movement of a device or object, it is, therefore, necessary first to determine all the forces that act on that device. In robots and manipulators, it is all the more important to know their real movement as they replace the man in heavy, daily, repetitive, tiring work. The known external forces acting on the studied manipulator, that is, the inertial forces, are initially calculated by means of the masses of the manipulator mechanism and their accelerations and then may be determined through specific analytical equations and the unknown internal forces of the system acting on the kinematic couplings of the manipulating mechanism considered.

Keywords: Machines, Mechanisms, Industrial Robots, Automation, Applied Computing, Forces, Dynamics, Robots and Manipulators

Introduction

Manipulating mechanisms have the important role of moving an object from one place to another. Robotic manipulators do this repeatedly thousands of times a day without getting tired or ruining without breaks or vacations. From this point of view, we can no longer speak of the fact that robots steal human labor, when they actually replace man in hard or very heavy, repetitive labors, sometimes sustained in gas or toxic, chemical or radioactive environments, or in dangerous environments, such as dyeing or very dangerous as mined land. Robots can also work in the cosmos by helping humans conquer space, a basic humanitarian mission, or they can carry out various major operations at deep depths beneath the earth or the ocean floor. For example, they can mount or weld an underwater pipe under conditions impossible for humans because the pressure at that depth cannot be borne by any being.

Determining the forces acting within a mechanism is an extremely important problem because on the basis of these forces calculated before designing the mechanism, the functional constructive parameters of that device can be predicted. The higher the forces that will act in the kinematic coupler of the mechanism, the more rigid the structure of the mechanism will be required, each element being designed to withstand both static and dynamic loads in operation. Select the engine or, as the case may be, the required drive motors that can generate the necessary engine moments, which are superior to those in operation, pre-calculated using the previously determined mechanism forces. Forces in any device require all its components, the demands being generally higher during operation, increasing generally with the square of the main engine speed. The demands depend very much on the inertial forces in the mechanism, which in turn increase with the speed of the mechanism (drive motor speed). Each coupling requires a certain type of movement and has an important influence on the dynamic range of the area and the entire kinematic chain. For this reason, the forces in the mechanism depend primarily on the type of the mechanism, its couplings and its elements, but also the speed of the leading element.

The known external forces acting within any mechanism are those of inertia, commonly called the torso of inertial forces. At the transport manipulator mechanism presented in this paper, the inertial forces are calculated using the relations of the system 1 (In the schemes presented they are represented by a continuous line (green), while the unknown forces to be determined, i.e., the reactions from the kinematic couplers, are represented by broken line (red color)).

Force calculations are performed inversely than kinematic, i.e., starting with the last module of the mechanism (RRT) the relational system 2, the relational system 3 continues with the middle module (RRR) and completes with the leading element (system relations 4).

Using the known external forces, the unknown inner forces, that is, the reactions from the kinematic couplers and the motor moment required to be applied to the leading element 1 are analyzed analytically.

A robot is a mechanical or virtual, artificial operator. The robot is a system composed of several elements: mechanical, sensors and actuators as well as a steering mechanism. The mechanics determine the appearance of the robot and the possible movements during operation. Sensors and actors are used when interacting with the system environment. The targeting mechanism ensures that the robot accomplishes its goal successfully, assessing for example sensor information. This mechanism regulates the engines and plans the movements to be made. Robots with human form are called androids.

The Greek mathematician, Archytas (Encyclopædia Britannica), has, according to some accounts, built one of these first automata: a vapor-driven pigeon that could fly alone. This wooden cavern was filled with air under pressure. It had a valve that allowed opening and closing by a counterweight. There have been many models over the centuries. Some made work easier and others served to people's amusement.

With the discovery of the 14th century mechanical clock, new and complex possibilities have opened up. Not long afterwards, the first machines appeared, which resembled the robots today. But it was only possible that the movements followed one another without the need for manual intervention in that system.

The development of electrical engineering in the twentieth century has brought about a development of robotics. The first mobile robots include the Elmer and Elsie system built by William Gray Walter in 1948 (Norman's, 2018). These tricycles could point to a light source and recognize collisions in the surroundings.

The year 1956 is considered as the birthday of the industrial robot. George Devol has filed this year's US application for a patent for "scheduled article transfer". A few years later he built together with Joseph Engelberger UNIMATE (Engelberger, J.F., The Father of Robotics). This robot of approx. two tons was first introduced into the installation of TV iconoscopes and then found its way into the automotive industry. The programs for this robot were saved in the form of directional commands for motors on a magnetic cylinder. Since then, industrial robots such as UNIMATE have been introduced in many production areas and are continually being developed further to cope with the complex demands imposed on them.

Robots are mainly made by combining disciplines: mechanical, electrotechnical and computer science. Meanwhile, it was created from their mechatronic connection. To build autonomous systems (to find solutions), it is necessary to link as many disciplines as possible to robotics. Here the emphasis is placed on the linkage between the concepts of artificial intelligence or neuroinformatics (part of computer science) as well as their biochemical biological ideal (part of biology). The link between biology and technology has developed into bionics.

The most important components of the robots are the sensors, which allow their mobility in the environment and a more precise routing. A robot does not necessarily have to be able to act autonomously, which distinguishes between autonomous and telegraph robots.

The image of humanoid robots took shape in literature, especially in the novels of Isaac Asimov in the 1940s. These robots were for a long time unrealistic. Many important issues have to be solved for their achievement. They must act and react autonomously in the environment, their mobility being restricted to the two legs as locomotion. Besides, they still need to be able to work with their arms and hands. Since 2000, basic issues seem to be resolved (with the emergence of ASIMO (Honda) for example; Honda's, humanoid robot). Meanwhile, new developments are emerging in this area. Humanoid robots can be described as stepping robots.

The household robot works autonomously in the household. Known applications are vacuum cleaner (manufactured by Electrolux, Siemens or iRobot), lawnmower, a robot washing the windows (Bill Gates, 2013).

Exploratory robots are robots that operate in hard-to-reach and dangerous locations teleghidated or partially autonomous. They can work for example in a region in military conflict, on the Moon or on Mars. A geared navigation from the ground in the last two cases is impossible due to distance. Communication signals arrive at their destination in a few hours and their reception lasts as long. In such situations robots must be programmed with several types of behavior, from which they choose the most appropriate and execute it.

This type of robot equipped with sensors has also been used to research pyramid wells. Several cryobots have already been tested by NASA in Antarctica. This type of robot can reach up to 3,600 m through ice. Cryobots can thus be used in polar head research on Mars and Europe in the hope of alien life discoveries.

Robots are also called mobile units. These units can detect and defuse or destroy bombs or me (eg the TALON robot). There are also robots that help search for people buried after earthquakes. Meanwhile, the so-called killer-robots, some humanoid monsters able to fight with any enemy (human, animal, other robots), have been deployed in the armies, using increasingly sophisticated weapons.

George Devol recorded the first patent for an industrial robot in 1954. Current industrial robots are not usually mobile. By their form and function, their operational scope is restricted. They were introduced for the first time on the production line of General Motors in 1961. Industrial robots were first used in Germany for welding works since 1970.

Industrial robots include portable robots that are introduced into wafer production, rosin casting, or measurements. Currently, industrial robots are also running maneuvering issues (manipulators).

In 1940 – occurs a mention of the use of the first synchronous manipulators for the handling of radioactive substances (Hazards from radioactive materials, BBC; Handling Radioactive Materials).

Perhaps some of today's most used robots are the manipulating robots because in all the main industrial operations there are intermediate and manipulation operations, i.e., various maneuvers and positioning of objects. Manipulation of objects actually refers to their movement from one place to another for positioning.

In the paper (Aversa *et al*., 2017b) a manipulative forging robot is described in terms of geometric, cinematic, but also of the forces acting in its main mechanism.

The technique of industrial robots and also industrial materials used in robotics and mechatronics are generally described in works (Aversa *et al*., 2016a; 2016b; 2016c; 2016d; 2017a; 2017b; 2017c; 2017d; 2017e; Berto *et al*., 2016a; 2016b; 2016c; 2016d; Mirsayar *et al*., 2017).

In papers (Petrescu and Petrescu, 2016 c; 2016 d) the dynamics that act in various mechanisms are presented and studied.

In the papers (Petrescu *et al*., 2017 t-ae) are specified the essential parameters of industrial robots and manipulators.

The main parameters of a simple manipulator mechanism, its basic geometry and kinematics, but especially the way of determining the forces acting in this type of mechanisms are presented.

It starts directly with the presentation of the analytical calculations that can determine the forces of the main mechanism of a simple conveyor manipulator.

Such manipulating conveyor mechanisms are at the basis of all types of robots and industrial manipulators, which is why it is imperative to study such a mechanism (Aversa *et al*., 2016a; 2016b; 2016c; 2016d; 2017a; 2017b; 2017c; 2017d; 2017e; Berto *et al*., 2016a; 2016b; 2016c; 2016d; Mirsayar *et al*., 2017; Cao *et al*., 2013; Dong *et al*., 2013; De Melo *et al*., 2012; Garcia *et al*., 2007; Garcia-Murillo *et al*., 2013; He *et al*., 2013; Lee, 2013; Lin *et al*., 2013; Liu *et al*., 2013; Padula and Perdereau, 2013; Perumaal and Jawahar, 2013; Petrescu and Petrescu, 1995a; 1995b; 1997a; 1997b; 1997c; 2000a; 2000b; 2002a; 2002b; 2003; 2005a; 2005b; 2005c; 2005d; 2005e, 2016a; 2016b; 2016c; 2016d; 2016e; 2013; 2012a; 2012b; 2011; Petrescu *et al*., 2009; 2016 a-e; 2017 a-ae; Petrescu and Calautit, 2016 a-b; Reddy *et al*., 2012; Tabaković *et al*., 2013; Tang *et al*., 2013; Tong *et al*., 2013; Wang *et al*., 2013; Wen *et al*., 2012; Antonescu and Petrescu, 1985; 1989; Antonescu *et al*., 1985a; 1985b; 1986; 1987; 1988; 1994; 1997; 2000a; 2000b; 2001).

Materials and Methods

The known external forces acting within any mechanism are those of inertia, commonly called the torso of inertial forces (Fig. 1). At the transport manipulator mechanism presented in this paper, the inertial forces are calculated using the relations of the system 1 (In the schemes presented they are represented by a continuous line (green), while the unknown forces to be determined, i.e., the reactions from the kinematic couplers, are represented by broken line (red color)).

Force calculations are performed inversely than kinematic, i.e., starting with the last module of the mechanism (RRT) the relational system 2, the relational system 3 continues with the middle module (RRR) and completes with the leading element (system relations 4).

Using the known external forces, the unknown inner forces, that is, the reactions from the kinematic couplers and the motor moment required to be applied to the leading element 1 are analyzed analytically.

For the planar operator manipulator mechanism of Fig. 1 we can say (we know): l1= 0,1[m]; l3 = 0,8[m]; l2 = 1,1[m]; a = 0,5[m]; b = 0,6[m]; l4 = 0,7[m]; xO = 0[m]; yO = 0[m]; yE = 0[m]; xA = -0,5[m]; yA = -0,6[m]; FI1[deg]. Required: FI2 [deg]; FI3 [deg]; FI4 [deg]; xE [m].

The known external forces acting within any mechanism are those of inertia, together called the torso of inertial forces (Fig. 2).

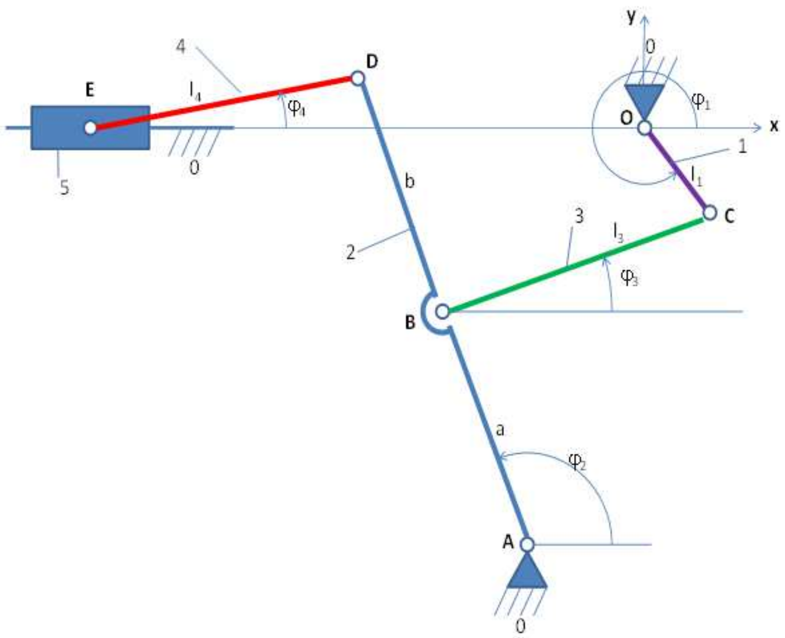

Fig. 1: The geometric scheme of a planar manipulator

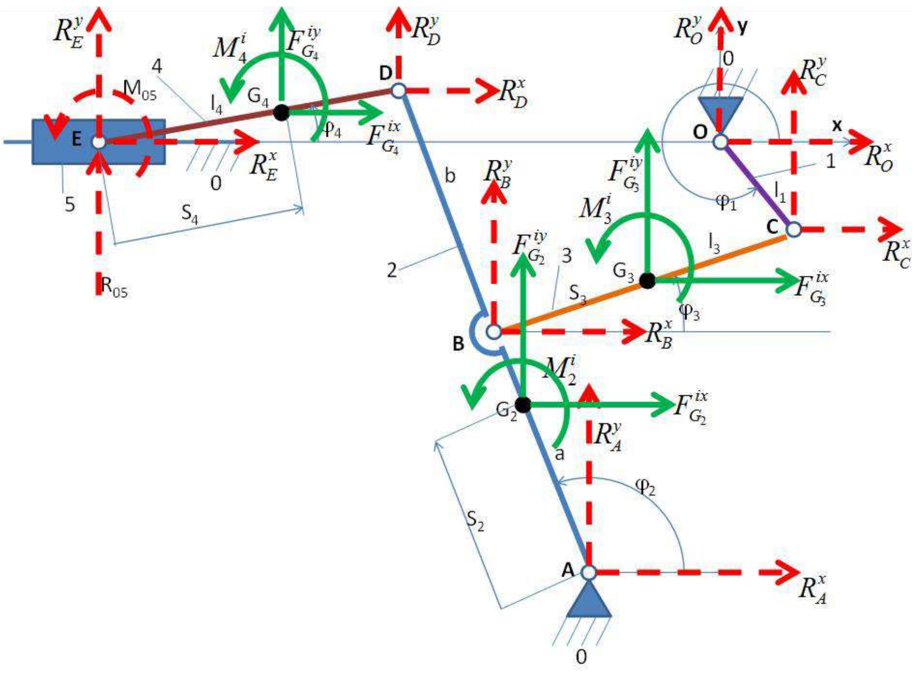

Fig. 2: The forces acting within a simple conveyor manipulator

At the transport manipulator mechanism presented in this paper, the inertial forces are calculated using the relations of the system 1 (In the schemes presented they are represented by a continuous line (green), whereas the unknown forces to be determined, i.e., the reactions from the kinematic couplers, are represented by broken line (red color)).

$$\begin{cases} \begin{cases} F_{G_4}^{ix} = -m_4 \cdot \ddot{x}_{G_4} \\ F_{G_4}^{iy} = -m_4 \cdot \ddot{y}_{G_4} \\ M_4^i = -J_{G_4} \cdot \ddot{\varphi}_4 \\ F_{G_5}^{ix} = -m_5 \cdot \ddot{x}_{G_5} \end{cases} & \begin{cases} F_{G_2}^{ix} = -m_2 \cdot \ddot{x}_{G_2} \\ F_{G_2}^{iy} = -m_2 \cdot \ddot{y}_{G_2} \\ M_2^i = -J_{G_2} \cdot \ddot{\varphi}_2 \end{cases} & \begin{cases} F_{G_3}^{ix} = -m_3 \cdot \ddot{x}_{G_3} \\ F_{G_3}^{iy} = -m_3 \cdot \ddot{y}_{G_3} \\ M_3^i = -J_{G_3} \cdot \ddot{\varphi}_3 \end{cases} \end{cases} \tag{1}$$

Forces calculations are carried out inversely to the kinematic ones, i.e., starting with the last module of the mechanism (RRT) the relational system 2, the relational system 3 continues with the middle module (RRR) and completes with the leading element (system relations 4).

$$\begin{cases}\begin{cases}\sum M_D^{(4,5)}=0\Rightarrow -R_{05}\cdot(x_D-x_E)+F_{G_5}^{ix}\cdot(y_D-y_E)\\ +F_{G_4}^{ix}\cdot(y_D-y_{G_4})-F_{G_4}^{iy}\cdot(x_D-x_{G_4})+M_4^i=0\Rightarrow\\ \Rightarrow R_{05}=\dfrac{F_{G_5}^{ix}\cdot(y_D-y_E)+F_{G_4}^{ix}\cdot(y_D-y_{G_4})-F_{G_4}^{iy}\cdot(x_D-x_{G_4})+M_4^i}{x_D-x_E}\end{cases}\\ \begin{cases}\sum F^{y(5)}=0\Rightarrow R_{05}+R_{45}^y=0\Rightarrow R_{45}^y=-R_{05}\Rightarrow R_E^y\equiv R_{54}^y=-R_{45}^y=R_{05}\\ \sum F^{x(5)}=0\Rightarrow F_{G_5}^{ix}+R_{45}^x=0\Rightarrow R_{45}^x=-F_{G_5}^{ix}\Rightarrow R_E^x\equiv R_{54}^x=-R_{45}^x=F_{G_5}^{ix}\\ \sum F^{y(4)}=0\Rightarrow R_{54}^y+F_{G_4}^{iy}+R_{24}^y=0\Rightarrow R_{24}^y=-R_{54}^y-F_{G_4}^{iy}=-R_{05}-F_{G_4}^{iy}\\ \Rightarrow R_D^y\equiv R_{42}^y=-R_{24}^y=R_{05}+F_{G_4}^{iy}\sum F^{x(4)}=0\Rightarrow R_{54}^x+F_{G_4}^{ix}+R_{24}^x=0\\ \Rightarrow R_{24}^x=-R_{54}^x-F_{G_4}^{ix}=-F_{G_5}^{ix}-F_{G_4}^{ix}\Rightarrow R_D^x\equiv R_{42}^x=-R_{24}^x=F_{G_5}^{ix}+F_{G_4}^{ix}\end{cases}\end{cases}\tag{2}$$

$$\begin{cases}\begin{cases}\sum M_B^{(2)}=0\Rightarrow R_{02}^x\cdot(y_B-y_A)+R_{02}^y\cdot(x_A-x_B)-R_{42}^x\cdot(y_D-y_B)\\ -R_{42}^y\cdot(x_B-x_D)+F_{G_2}^{ix}\cdot(y_B-y_{G_2})+F_{G_2}^{iy}\cdot(x_{G_2}-x_B)+M_2^i=0\\ \\ \sum M_C^{(2,3)}=0\Rightarrow R_{02}^x\cdot(y_C-y_A)-R_{02}^y\cdot(x_C-x_A)-\\ -R_{42}^x\cdot(y_D-y_C)-R_{42}^y\cdot(x_C-x_D)+F_{G_2}^{ix}\cdot(y_C-y_{G_2})\\ -F_{G_2}^{iy}\cdot(x_C-x_{G_2})+M_2^i+F_{G_3}^{ix}\cdot(y_C-y_{G_3})-F_{G_3}^{iy}\cdot(x_C-x_{G_3})+M_3^i=0\end{cases}\\ \begin{cases}\begin{cases}a_{11}\cdot R_{02}^x+a_{12}\cdot R_{02}^y=a_1\\ a_{21}\cdot R_{02}^x+a_{22}\cdot R_{02}^y=a_2\end{cases}\\ a_{11}=y_B-y_A\quad a_{12}=x_A-x_B\\ a_1=R_{42}^x\cdot(y_D-y_B)+R_{42}^y\cdot(x_B-x_D)+F_{G_2}^{ix}\cdot(y_{G_2}-y_B)+F_{G_2}^{iy}\cdot(x_B-x_{G_2})-M_2^i\\ a_{21}=y_C-y_A\quad a_{22}=x_A-x_C\\ a_2=R_{42}^x\cdot(y_D-y_C)+R_{42}^y\cdot(x_C-x_D)+F_{G_2}^{ix}\cdot(y_{G_2}-y_C)+F_{G_2}^{iy}\cdot(x_C-x_{G_2})-M_2^i\\ +F_{G_3}^{ix}\cdot(y_{G_3}-y_C)+F_{G_3}^{iy}\cdot(x_C-x_{G_3})-M_3^i\\ \\ \Delta=\begin{vmatrix}a_{11}&a_{12}\\a_{21}&a_{22}\end{vmatrix}=a_{11}\cdot a_{22}-a_{12}\cdot a_{21}\\ \Delta_x=\begin{vmatrix}a_1&a_{12}\\a_2&a_{22}\end{vmatrix}=a_1\cdot a_{22}-a_2\cdot a_{12}\quad \Delta_y=\begin{vmatrix}a_{11}&a_1\\a_{21}&a_2\end{vmatrix}=a_2\cdot a_{11}-a_1\cdot a_{21}\\ R_A^x\equiv R_{02}^x=\dfrac{\Delta_x}{\Delta}\quad R_A^y\equiv R_{02}^y=\dfrac{\Delta_y}{\Delta}\end{cases}\\ \begin{cases}\sum F^{x(2)}=0\Rightarrow R_{32}^x+R_{42}^x+R_{02}^x=0\Rightarrow R_{32}^x=-R_{42}^x-R_{02}^x\Rightarrow R_B^x\equiv R_{23}^x=-R_{32}^x\\ \sum F^{y(2)}=0\Rightarrow R_{32}^y+R_{42}^y+R_{02}^y=0\Rightarrow R_{32}^y=-R_{42}^y-R_{02}^y\Rightarrow R_B^y\equiv R_{23}^y=-R_{32}^y\\ \sum F^{x(3)}=0\Rightarrow R_{23}^x+F_{G_3}^{ix}+R_{13}^x=0\Rightarrow R_{13}^x=-R_{23}^x-F_{G_3}^{ix}\Rightarrow R_C^x\equiv R_{31}^x=-R_{13}^x\\ \sum F^{y(3)}=0\Rightarrow R_{23}^y+F_{G_3}^{iy}+R_{13}^y=0\Rightarrow R_{13}^y=-R_{23}^y-F_{G_3}^{iy}\Rightarrow R_C^y\equiv R_{31}^y=-R_{13}^y\end{cases}\end{cases}\tag{3}$$

$$\begin{cases} \begin{cases} \sum M_O^{(1)} = 0 \Rightarrow M_m + R_{31}^x \cdot (y_O - y_C) + R_{31}^y \cdot (x_C - x_O) = 0 \Rightarrow \\ \Rightarrow M_m = R_{31}^x \cdot (y_C - y_O) + R_{31}^y \cdot (x_O - x_C) \end{cases} \\ \sum F^{x(1)} = 0 \Rightarrow R_{01}^x + R_{31}^x = 0 \Rightarrow R_O^x \equiv R_{01}^x = -R_{31}^x \\ \sum F^{y(1)} = 0 \Rightarrow R_{01}^y + R_{31}^y = 0 \Rightarrow R_O^y \equiv R_{01}^y = -R_{31}^y \end{cases} \quad (4)$$

In the relational system 5, the kinematic equations of the weight centers for the elements 2, 3 and 4 are written. The center of gravity of the element 1 coincides with the point *O* because the element 1 is statically totally balanced and the center of gravity of the element 5 coincides with the joint *E* for which moment *M*05 is null. The relationship with which the masses and inertial masses of elements 2, 3 and 4 are determined is also now described:

$$\begin{cases} \left\{ s_4 = \frac{2}{3} \cdot l_4 \quad s_2 = \frac{1}{3} \cdot (a+b) \quad s_3 = \frac{2}{3} \cdot l_3 \right. \\ \begin{cases} \begin{cases} x_{G_3} = x_B + s_3 \cdot \cos\varphi_3 \\ y_{G_3} = y_B + s_3 \cdot \sin\varphi_3 \end{cases} \begin{cases} \dot{x}_{G_3} = \dot{x}_B - s_3 \cdot \sin\varphi_3 \cdot \dot{\varphi}_3 \\ \dot{y}_{G_3} = \dot{y}_B + s_3 \cdot \cos\varphi_3 \cdot \dot{\varphi}_3 \end{cases} \\ \begin{cases} \ddot{x}_{G_3} = \ddot{x}_B - s_3 \cdot \cos\varphi_3 \cdot \dot{\varphi}_3^2 - s_3 \cdot \sin\varphi_3 \cdot \ddot{\varphi}_3 \\ \ddot{y}_{G_3} = \ddot{y}_B - s_3 \cdot \sin\varphi_3 \cdot \dot{\varphi}_3^2 + s_3 \cdot \cos\varphi_3 \cdot \ddot{\varphi}_3 \end{cases} \\ \begin{cases} x_{G_2} = x_A + s_2 \cdot \cos\varphi_2 \\ y_{G_2} = y_A + s_2 \cdot \sin\varphi_2 \end{cases} \begin{cases} \dot{x}_{G_2} = -s_2 \cdot \sin\varphi_2 \cdot \dot{\varphi}_2 \\ \dot{y}_{G_2} = s_2 \cdot \cos\varphi_2 \cdot \dot{\varphi}_2 \end{cases} \\ \begin{cases} \ddot{x}_{G_2} = -s_2 \cdot \cos\varphi_2 \cdot \dot{\varphi}_2^2 - s_2 \cdot \sin\varphi_2 \cdot \ddot{\varphi}_2 \\ \ddot{y}_{G_2} = -s_2 \cdot \sin\varphi_2 \cdot \dot{\varphi}_2^2 + s_2 \cdot \cos\varphi_2 \cdot \ddot{\varphi}_2 \end{cases} \\ \begin{cases} x_{G_4} = x_E + s_4 \cdot \cos\varphi_4 \\ y_{G_4} = y_E + s_4 \cdot \sin\varphi_4 \end{cases} \begin{cases} \dot{x}_{G_4} = \dot{x}_E - s_4 \cdot \sin\varphi_4 \cdot \dot{\varphi}_4 \\ \dot{y}_{G_4} = s_4 \cdot \cos\varphi_4 \cdot \dot{\varphi}_4 \end{cases} \\ \begin{cases} \ddot{x}_{G_4} = \ddot{x}_E - s_4 \cdot \cos\varphi_4 \cdot \dot{\varphi}_4^2 - s_4 \cdot \sin\varphi_4 \cdot \ddot{\varphi}_4 \\ \ddot{y}_{G_4} = -s_4 \cdot \sin\varphi_4 \cdot \dot{\varphi}_4^2 + s_4 \cdot \cos\varphi_4 \cdot \ddot{\varphi}_4 \end{cases} \end{cases} \\ \begin{cases} \begin{cases} x_D = x_E + l_4 \cdot \cos\varphi_4 \\ y_D = y_E + l_4 \cdot \sin\varphi_4 \end{cases} \begin{cases} \dot{x}_D = \dot{x}_E - l_4 \cdot \sin\varphi_4 \cdot \dot{\varphi}_4 \\ \Rightarrow \dot{x}_E = \dot{x}_D + l_4 \cdot \sin\varphi_4 \cdot \dot{\varphi}_4 \\ \dot{y}_D = l_4 \cdot \cos\varphi_4 \cdot \dot{\varphi}_4 \Rightarrow \dot{\varphi}_4 = \dfrac{\dot{y}_D}{l_4 \cdot \cos\varphi_4} \end{cases} \\ \begin{cases} \ddot{x}_D = \ddot{x}_E - l_4 \cdot \cos\varphi_4 \cdot \dot{\varphi}_4^2 - l_4 \cdot \sin\varphi_4 \cdot \ddot{\varphi}_4 \\ \Rightarrow \ddot{x}_E = \ddot{x}_D + l_4 \cdot \cos\varphi_4 \cdot \dot{\varphi}_4^2 + l_4 \cdot \sin\varphi_4 \cdot \ddot{\varphi}_4 \\ \ddot{y}_D = -l_4 \cdot \sin\varphi_4 \cdot \dot{\varphi}_4^2 + l_4 \cdot \cos\varphi_4 \cdot \ddot{\varphi}_4 \\ \Rightarrow \ddot{\varphi}_4 = \dfrac{\ddot{y}_D + l_4 \cdot \sin\varphi_4 \cdot \dot{\varphi}_4^2}{l_4 \cdot \cos\varphi_4} \end{cases} \\ \begin{cases} m_2 = 0.3 \cdot (a+b) \quad m_3 = 0.3 \cdot l_3 \quad m_4 = 0.3 \cdot l_4 \\ J_{G_2} = \dfrac{m_2 \cdot (a+b)^2}{12} \quad J_{G_3} = \dfrac{m_3 \cdot l_3^2}{12} \quad J_{G_4} = \dfrac{m_4 \cdot l_4^2}{12} \end{cases} \end{cases} \end{cases} \quad (5)$$

The positions of the crank 1 are written with relations 6 and those of the RRR mechatronic module formed by the elements 2 and 3 are determined by the relational system 7.

$$\begin{cases} x_C = x_O + l_1 \cdot \cos\varphi_1 \\ y_C = y_O + l_1 \cdot \sin\varphi_1 \end{cases} \quad (6)$$

$$\begin{cases} e = x_C - x_A \;;\; f = y_C - y_A \;;\; l = \sqrt{e^2 + f} \\ \cos\varphi = \dfrac{e}{l} \;;\; \sin\varphi = \dfrac{f}{l} \\ \Rightarrow \varphi = \arccos(\cos\varphi) \cdot sign(\sin\varphi) \\ \cos A = \dfrac{l^2 + a^2 - l_3^2}{2a \cdot l} \\ ;\; \cos C = \dfrac{l^2 + l_3^2 - a^2}{2l \cdot l_3} \\ A = \arccos(\cos A); \quad C = \arccos(\cos C) \\ \varphi_2 = \varphi + A; \quad \varphi_3 \\ = \varphi - C; \quad x_D = x_A + l_2 \cdot \cos\varphi_2 \\ y_D = y_A + l_2 \cdot \sin\varphi_2 \end{cases} \quad (7)$$

It following then the calculation relations for the RRT mechatronic module positions (8):

$$\begin{cases} x_D = x_E + l_4 \cdot \cos\varphi_4 \\ y_D = y_E + l_4 \cdot \sin\varphi_4 \end{cases} => \begin{cases} x_D - x_E = l_4 \cdot \cos\varphi_4 \\ y_D - y_E = l_4 \cdot \sin\varphi_4 \end{cases}$$

$$=> (x_D - x_E)^2 + (y_D - y_E)^2 = l_4^2$$

$$=> (x_D - x_E)^2 = l_4^2 - (y_D - y_E)^2 => x_E$$

$$\begin{cases} x_E = x_D - \sqrt{l_4^2 - (y_D - y_E)^2} \;; \\ \cos\varphi_4 = \dfrac{x_D - x_E}{l_4} \;;\; \sin\varphi_4 = \dfrac{y_D - y_E}{l_4}; \\ \varphi_4 = \arccos(\cos\varphi_4) \cdot sign(\sin\varphi_4) \end{cases} \quad (8)$$

Results

The way in which FI2, FI3 and FI4 position angles vary depending on the position angle of the element 1, FI1, can be seen in the diagram in Fig. 3.

In Fig. 4 we can see the variance diagram of the known inertial forces according to the input angle FI1.

In the diagram of Fig. 5 are the inner forces of the kinematic couplers varying according to the input angle FI1 (The related calculation program is presented in the annex).

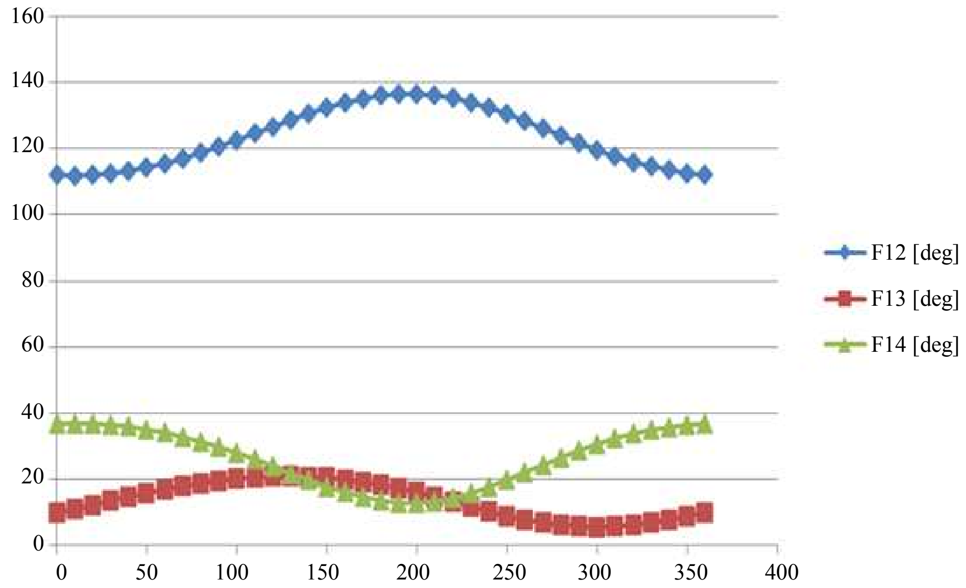

Fig. 3: FI2, FI3 and FI4 position angles vary depending on the position angle of the element 1, FI1

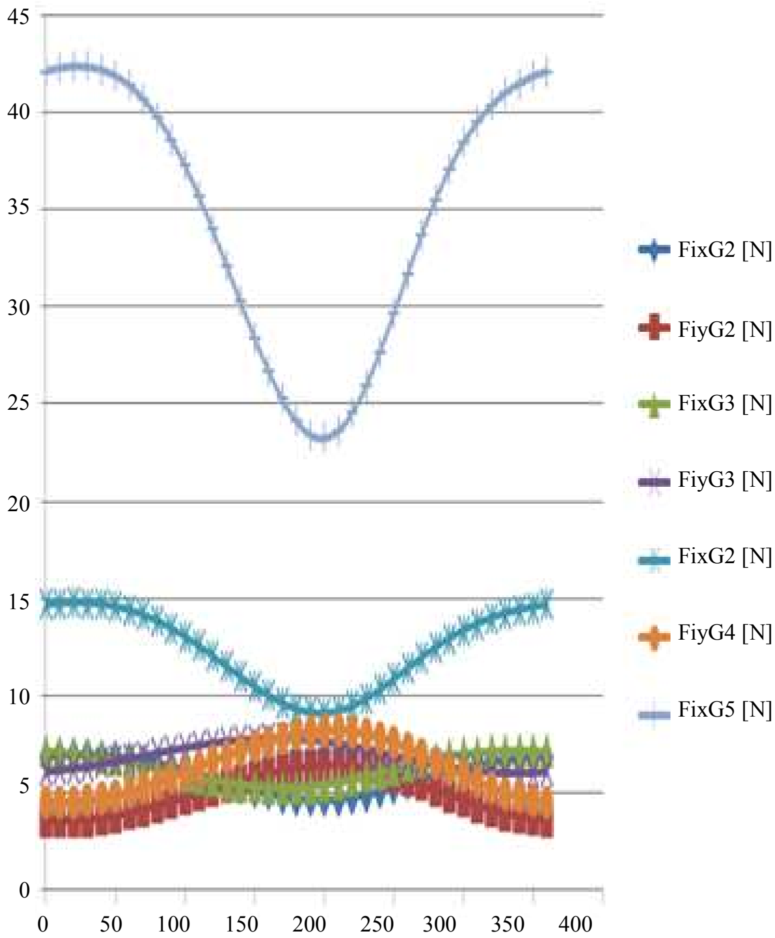

Fig. 4: The variance diagram of the known inertial forces according to the input angle FI1

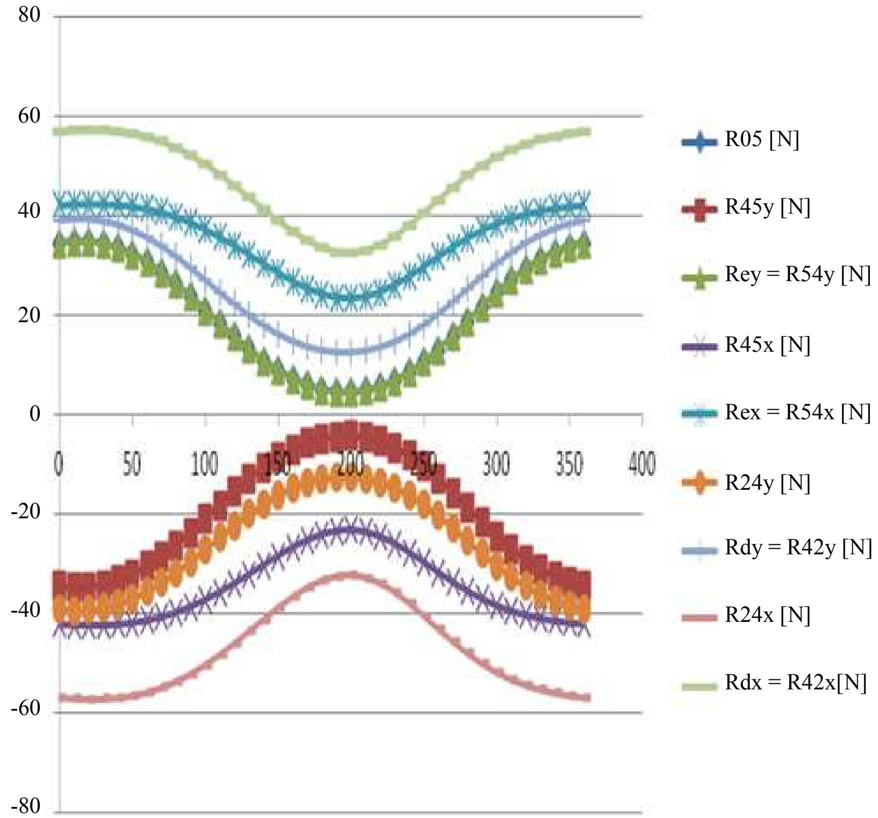

Fig. 5: In the diagram of Figure 5 are the inner forces of the kinematic couplers varying according to the input angle FI1

Discussion

Forces acting within any device or car have an important role because they are the ones that define the real movement of that device, the dynamic movement, movement that is very different from the cinematic imaginable by geometric-kinematic engineering calculations. To know the real movement of a device or object, it is, therefore, necessary first to determine all the forces that act on that device. In robots and manipulators, it is all the more important to know their real movement as they replace the man in heavy, daily, repetitive, tiring work. The known external forces acting on the studied manipulator, that is, the inertial forces, are initially calculated by means of the masses of the manipulator mechanism and their accelerations and then may be determined through specific analytical equations and the unknown internal forces of the system acting on the kinematic couplings of the manipulating mechanism considered.

Conclusion

The forces acting on the RRR module and on the leading element 1 (crank) are generally higher than those acting on the RRT end module, due to the constructive way of the mechanism, but also to the reduction of forces by using a translation coupler in the last kinematic module. Knowing the forces acting on the mechanism can determine both the dynamics of the mechanism and its loads so that the mechanism is correctly designed and especially proportional to be able to withstand the various dynamic loads during its use for a while longer. At the same time it is possible to determine the necessary motor torque during the entire energy cycle and thus choose the most satisfactory motor for the presented mechanism.

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Author's Contributions

All the authors contributed equally to prepare, develop and carry out this manuscript.

Ethics

This article is original and contains unpublished material. Authors declare that are not ethical issues and no conflict of interest that may arise after the publication of this manuscript.

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