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Presents the Kinematics and Forces at a Basic Anthropomorphic Robot

Relly Victoria Virgil Petrescu

ARoTMM-IFToMM, Bucharest Polytechnic University, Bucharest, (CE), Romania

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Email: rvvpetrescu@gmail.com

Abstract: The basic structure of the anthropomorphic robots used today massively in 80-90% cases from the industrial robots will be presented briefly, with the highlighting of an original method for determining the kinematics of the basic 3R module and with highlighting the forces at the basic structure set in the discussion. Some representative examples of calculation will be remembered as results. The paper is a basic one in the field and performs a recapitulation of how the basic anthropomorphic structures 3R are analyzed or designed correctly and quickly.

Keywords: Robots, Mechatronic Systems, Structure, Kinematics, Machines, Base Structures

Introduction

The basic structure of the anthropomorphic robots used today massively in 80-90% cases from the industrial robots will be presented briefly, with the highlighting of an original method for determining the kinematics of the basic 3R module and with highlighting the forces at the basic structure set in the discussion. Some representative examples of calculation will be remembered as results. The paper is a basic one in the field and performs a recapitulation of how the basic anthropomorphic structures 3R are analyzed or designed correctly and quickly.

Such repeated manipulations of heavy and dangerous objects can be done only with the help of a manipulator, which can be a crane, a specially designed trolley, a complicated robot or a simple manipulator as is the case for the one presented in the paper.

Workers are prevented from using it to get various diseases because of the repeated lifting of heavy objects. In the past, an interior crane built on different systems walks through the respective hall to carry the heavy objects.

High-performance machine monitoring robots make a variety of operations efficient, such as sand casting, injection molding, cutting, machining and assembly of small parts. Top providers should have solutions for every production scenario imaginable, from the smallest to the largest and in any cell configuration. It should also offer a full range of local and international support services available as soon as you need them.

Compact and equipped with up to six axes, certain types of robots are perfectly suited for the surveillance of small autonomous cells. In addition, their powerful controller can control the entire cell, as well as additional peripheral axes (Fig. 1).

Since space is already limited in most production units, many machine-monitoring robots have a small footprint. They also have standard equipment for protection against water and dust and the cables are drawn through the joint, so as not to be exposed to dangers. Some manufacturers also offer small models that are installed in the machine tool (Fig. 2).

Fig. 1: Compact and equipped with up to six axes, certain types of robots are perfectly suited for the surveillance

Fig. 2: Compact solutions

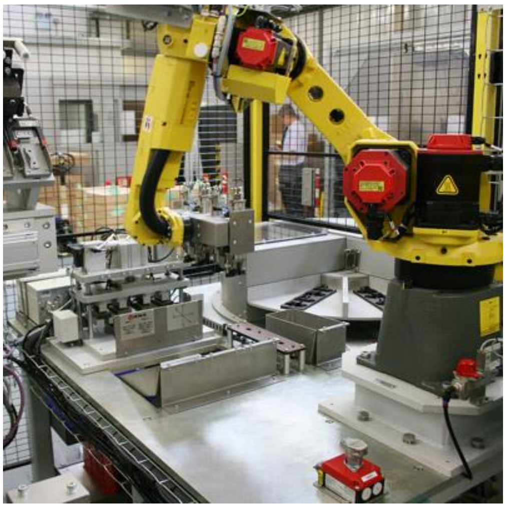

Fig. 3: Use of robots in a variety of industrial operations

Fig. 4: Faster tool changes

One can use robots for a variety of additional cell-related operations, such as quality control, specification checking and surface inspection (Fig. 3).

Due to the wide range of options for installing instrument replacement stations, including suspended mounting, some types of robots can be used for very efficient instrument replacement. Because they can work with a wide variety of tools, these models can handle any number of instruments, regardless of their weight (Fig. 4).

Robots are priceless when it comes to injection molding. From the disassembly of the parts to the cutting of the screws, unloading, labeling, laser treatment and adding inserts, they increase the efficiency in a variety of operations and prevent the risk of damage (Fig. 5).

With a range of rail, floor, wall and ceiling mount options to save space and expand your robot's workspace, some robot models are ideally suited for multi-tool monitoring - improving your performance and maximizing production time (Fig. 6).

To speed up processes involving containerized parts, container selection solutions based on visual detection allow robots to identify, select and load parts from a container. Sometimes improving 99.97 percent operating times, this technology dramatically accelerates even the most complicated of the selection operations (Fig. 7).

Machine surveillance is an operation that many people are not willing to do. In contrast, quality robots provide 720 h of perfect production, multiple operations between cells, loading and unloading parts and the ability to connect up to eight machines (Fig. 8).

Extremely lightweight and compact, dedicated monitoring robots available from some manufacturers have been created specifically for high-speed applications such as machine monitoring. Due to the compact arms, the protected harness and the 7 kg payload, these experts are ideal for production operations that require access to small spaces and where maneuver space is reduced (Fig. 9).

Manufacturers with proven expertise in the field of visual detection systems can equip robots with intelligent visual detection options, which enable a wide range of machine surveillance operations. Options often include 2D visual detection for track location, 3D visual detection for track detection, positioning and orientation, line tracking for conveyors and area sensors for sorting boxes (Fig. 10).

On robots equipped with an optical scanner, the innovative security software provided by some manufacturers allows you to forgo the traditional constraints that take up a lot of space, such as fences and safety hardware. Instead, this feature prevents the robot from accessing specific areas and, by slowing it down, allows the operator to enter the workspace without interrupting production (Fig. 11).

In the case of operations involving multiple processes, the best robots quickly replace the claws to maximize production time (Fig. 12).

Fig. 5: Injection molding

Fig. 6: Load more machinery

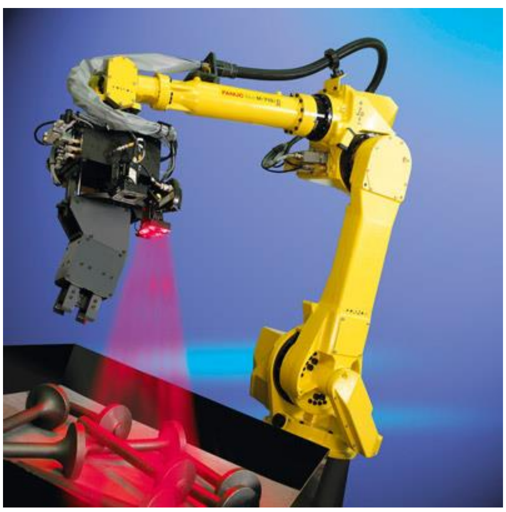

Fig. 7: Randomly load objects quickly

Fig. 8: Fully automated processing

Fig. 9: Experts in machinery supervision

Fig. 10: Expand your visual ability

Fig. 11: Great security but invisible

Fig. 12: Change the claws quickly

Fig. 13: A full range of flexible standalone solutions makes machine monitoring robots a very viable option for small businesses. Being cheaper and easier to use than you can imagine, they offer significant benefits even for small production cycles

A full range of flexible standalone solutions makes machine monitoring robots a very viable option for small businesses (Fig. 13).

Being cheaper and easier to use than you can imagine, they offer significant benefits even for small production cycles. This is especially the case where the tedious, dirty and dangerous nature of manual surveillance of machines makes it difficult to find and retain manual operators. In addition, after they are created, machine monitoring programs can be restored from memory whenever new commands are received. We can firmly state that today Fanuc robots are respected as the world's number one leading company as well as at the beginning of the global robotization of the years 1970-1980. How to analyze or design these robots today indispensable, how to be selected, then implemented and maintained, will be seen from the rapid study carried out in this paper (Aabadi, 2019; Antonescu and Petrescu, 1985; 1989; Antonescu *et al*., 1985a; 1985b; 1986; 1987; 1988; 1994; 1997; 2000a; 2000b; 2001; Aversa *et al*., 2017a; 2017b; 2017c; 2017d; 2017e; 2016a; 2016b; 2016c; 2016d; 2016e; 2016f; 2016g; 2016h; 2016i; 2016j; 2016k; 2016l; 2016m; 2016n; 2016o; Cao *et al*., 2013; Dong *et al*., 2013; Comanescu, 2010; Franklin, 1930; He *et al*., 2013; Lee, 2013; Lin *et al*., 2013; Liu *et al*., 2013; Padula and Perdereau, 2013; Perumaal and Jawahar, 2013; Petrescu, 2011; 2015a; 2015b; Petrescu and Petrescu, 1995a; 1995b; 1997a; 1997b; 1997c; 2000a; 2000b; 2002a; 2002b; 2003; 2005a; 2005b; 2005c; 2005d; 2005e; 2011a; 2011b; 2012a; 2012b; 2013a; 2013b; 2013c; 2013d; 2013e; 2016a; 2016b; 2016c; Petrescu *et al*., 2009; 2016; 2017a; 2017b; 2017c; 2017d; 2017e; 2017f; 2017g; 2017h; 2017i; 2017j; 2017k; 2017l; 2017m; 2017n; 2017o; 2017p; 2017q; 2017r; 2017s; 2017t; 2017u; 2017v; 2017w; 2017x; 2017y; 2017z; 2017aa; 2017ab; 2017ac; 2017ad; 2017ae; 2018a; 2018b; 2018c; 2018d; 2018e; 2018f; 2018g; 2018h; 2018i; 2018j; 2018k; 2018l; 2018m; 2018n; Rulkov *et al*., 2016; Agarwala, 2016; Babayemi, 2016; Ben-Faress *et al*., 2019; Gusti and Semin, 2016; Mohamed *et al*., 2016; Wessels and Raad, 2016; Maraveas *et al*., 2015; Khalil, 2015; Rhode-Barbarigos *et al*., 2015; Takeuchi *et al*., 2015; Li *et al*., 2015; Vernardos and Gantes, 2015; Bourahla and Blakeborough, 2015; Stavridou *et al*., 2015a; Ong *et al*., 2015; Dixit and Pal, 2015; Rajput *et al*., 2016; Rea and Ottaviano, 2016; Zurfi and Zhang, 2016a-b; Zheng and Li, 2016; Buonomano *et al*., 2016a; 2016b; Faizal *et al*., 2016; Ascione *et al*., 2016; Elmeddahi *et al*., 2016; Calise *et al*., 2016; Morse *et al*., 2016; Abouobaida, 2016; Rohit and Dixit, 2016; Kazakov *et al*., 2016; Alwetaishi, 2016; Riccio *et al*., 2016a; 2016b; Iqbal, 2016; Hasan and El-Naas, 2016; Al-Hasan and Al-Ghamdi, 2016; Jiang *et al*., 2016; Sepúlveda, 2016; Martins *et al*., 2016; Pisello *et al*., 2016; Jarahi, 2016; Mondal *et al*., 2016; Mansour, 2016; Al Qadi *et al*., 2016b; Campo *et al*., 2016; Samantaray *et al*., 2016; Malomar *et al*., 2016; Rich and Badar, 2016; Hirun, 2016; Bucinell, 2016;

Nabilou, 2016b; Barone *et al*., 2016; Bedon and Louter, 2016; Santos and Bedon, 2016; Fontánez *et al*., 2019; De León *et al*., 2019; Hypolite *et al*., 2019; Minghini *et al*., 2016; Bedon, 2016; Jafari *et al*., 2016; Orlando and Benvenuti, 2016; Wang and Yagi, 2016; Obaiys *et al*., 2016; Ahmed *et al*., 2016; Jauhari *et al*., 2016; Syahrullah and Sinaga, 2016; Shanmugam, 2016; Jaber and Bicker, 2016; Wang *et al*., 2016; Moubarek and Gharsallah, 2016; Amani, 2016; Shruti, 2016; Pérez-de León *et al*., 2016; Mohseni and Tsavdaridis, 2016; Abu-Lebdeh *et al*., 2016; Serebrennikov *et al*., 2016; Budak *et al*., 2016; Augustine *et al*., 2016; Jarahi and Seifilaleh, 2016; Nabilou, 2016a; You *et al*., 2016; AL Qadi *et al*., 2016a; Rama *et al*., 2016; Sallami *et al*., 2016; Huang *et al*., 2016; Ali *et al*., 2016; Kamble and Kumar, 2016; Saikia and Karak, 2016; Zeferino *et al*., 2016; Pravettoni *et al*., 2016; Bedon and Amadio, 2016; Mavukkandy *et al*., 2016; Yeargin *et al*., 2016; Madani and Dababneh, 2016; Alhasanat *et al*., 2016; Elliott *et al*., 2016; Suarez *et al*., 2016; Kuli *et al*., 2016; Waters *et al*., 2016; Montgomery *et al*., 2016; Lamarre *et al*., 2016; Daud *et al*., 2008; Taher *et al*., 2008; Zulkifli *et al*., 2008; Pourmahmoud, 2008; Pannirselvam *et al*., 2008; Ng *et al*., 2008; El-Tous, 2008; Akhesmeh *et al*., 2008; Nachiengtai *et al*., 2008; Moezi *et al*., 2008; Boucetta, 2008; Darabi *et al*., 2008; Semin and Bakar, 2008; Al-Abbas, 2009; Abdullah *et al*., 2009; Abu-Ein, 2009; Opafunso *et al*., 2009; Semin *et al*., 2009a; 2009b; 2009c; Zulkifli *et al*., 2009; Marzuki *et al*., 2015; Bier and Mostafavi, 2015; Momta *et al*., 2015; Farokhi and Gordini, 2015; Khalifa *et al*., 2015; Yang and Lin, 2015; Demetriou *et al*., 2015; Rajupillai *et al*., 2015; Sylvester *et al*., 2015a; Ab-Rahman *et al*., 2009; Abdullah and Halim, 2009; Zotos and Costopoulos, 2009; Feraga *et al*., 2009; Bakar *et al*., 2009; Cardu *et al*., 2009; Bolonkin, 2009a; 2009b; Nandhakumar *et al*., 2009; Odeh *et al*., 2009; Lubis *et al*., 2009; Fathallah and Bakar, 2009; Marghany and Hashim, 2009; Kwon *et al*., 2010; Aly and Abuelnasr, 2010; Farahani *et al*., 2010; Ahmed *et al*., 2010; Kunanoppadon, 2010; Helmy and El-Taweel, 2010; Qutbodin, 2010; Pattanasethanon, 2010; Fen *et al*., 2011; Thongwan *et al*., 2011; Theansuwan and Triratanasirichai, 2011; Al Smadi, 2011; Tourab *et al*., 2011; Raptis *et al*., 2011; Momani *et al*., 2011; Ismail *et al*., 2011; Anizan *et al*., 2011; Tsolakis and Raptis, 2011; Abdullah *et al*., 2011; Kechiche *et al*., 2011; Ho *et al*., 2011; Rajbhandari *et al*., 2011; Aleksic and Lovric, 2011; Kaewnai and Wongwises, 2011; Idarwazeh, 2011; Ebrahim *et al*., 2012; Abdelkrim *et al*., 2012; Mohan *et al*., 2012; Abam *et al*., 2012; Hassan *et al*., 2012; Jalil and Sampe, 2013; Jaoude and El-Tawil, 2013; Ali and Shumaker, 2013; Zhao, 2013; El-Labban *et al*., 2013; Djalel *et al*., 2013; Nahas and Kozaitis, 2013; Petrescu and Petrescu, 2014a; 2014b; 2014c; 2014d; 2014e; 2014f; 2014g; 2014h; 2014i; 2015a; 2015b; 2015c; 2015d; 2015e; 2016a; 2016b; 2016c; 2016d; Fu *et al*., 2015; Al-Nasra *et al*., 2015; Amer *et al*., 2015; Sylvester *et al*., 2015b; Kumar *et al*., 2015; Gupta *et al*., 2015; Stavridou *et al*., 2015b; Casadei, 2015; Ge and Xu, 2015; Moretti, 2015; Wang *et al*., 2015; Petrescu *et al*., 2017af-aj; 2018o-v; Petrescu, 2015c; 2018a; 2018b; Petrescu and Petrescu, 2018a; 2018b; Petrescu and Petrescu, 2014f; 2014g; 2014h; 2014i).

Materials and Methods

The structure of Fig. 14 is formed by two elements connected together by a plane of rotation of the fifth class in point C and having at the ends one or even two other rotating couplings of the fifth class.

Usually, the outer torque, from the point B, of the input, is also a plane of rotation torque as the inner one from C and in D it can only be a working point of the respective manipulator or robot or another outer torque can be caught, to which the end-effector is connected, i.e., the final device of the robot: It can be a gripper, that is, a gripping device, grabbing and handling, it can be a welding electrode, it can be a paint gun, a soldering hammer, any working device, or an arm can be used to extend the working capabilities of the robot; In point D, therefore, there may be no more couples, it may be a flat-rotation fifth-class couple as well as in points B and C, or it may be another spatial example couple; if the module consisting of the two arms 2 and 3 are used and/or only at, some mechanism, the simplest being the flat quadratic mechanism, or the articulated quadrilateral mechanism, which has the kinematic scheme presented in Fig. 15, then the right module studied will have a kinematic rotation torque, flat, fifth class and in point D, module 2-3 having in this case the designation of a structural group, type: Dyad 3R. This case being the most general (complete) we will begin within this theme, with him and we will study the direct and indirect kinematics of this module (dyad 3R) which we have seen that can be used, generalize to the vast majority of anthropomorphic robots. Classic robots are anthropomorphic, that is, serial robots and they have most of the rotational movements, the actions being done with rotary actuators (motors) step by step. All anthropomorphic structures are based on a 3R robot as shown in Fig. 16.

The idea is to greatly simplify the calculations and relations (even with the classical methods used), moving from the spatial study to the one in different planes. It can be seen that if we separate the rotational motion φ_{10} from the basic plane x0O0y0, decoupling it from the other rotational movements φ_{20} and φ_{30} we reach precisely our module, where the coupling in B is denoted here with A (O_2, being a point constructive), the coupling from C is denoted here by B (O_3 being a constructive point) and the coupling or working point of the D-effector is denoted here with M. This idea greatly eases the classical spatial calculations (see also the original spatial methods), especially those for inverse kinematics, as this is the most difficult, presented in the SMMSP course), turning them into flat calculations.

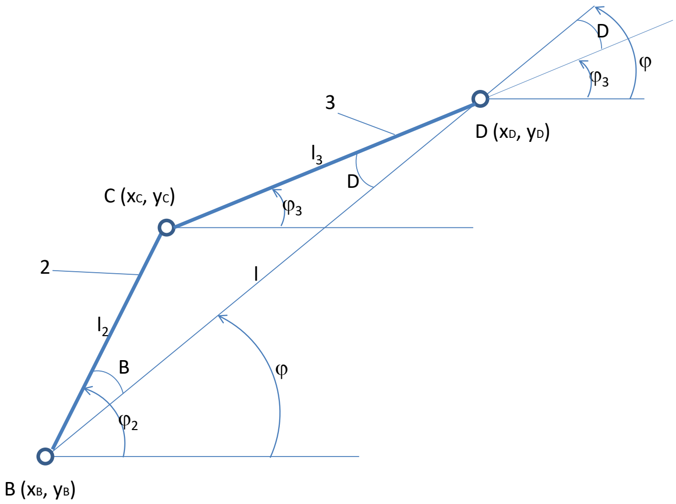

Fig. 14: The planar basic structure

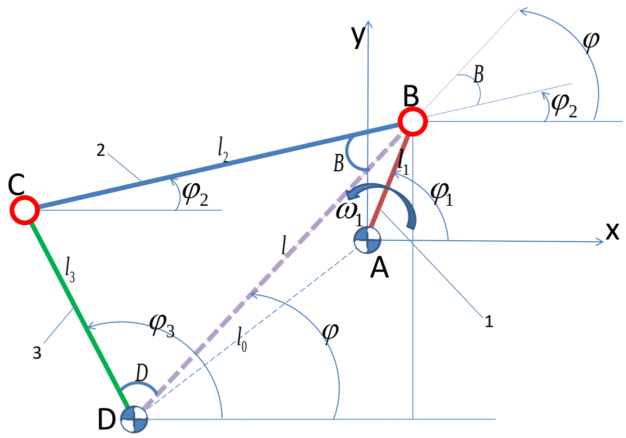

Fig. 15: An articulated quadrilateral mechanism

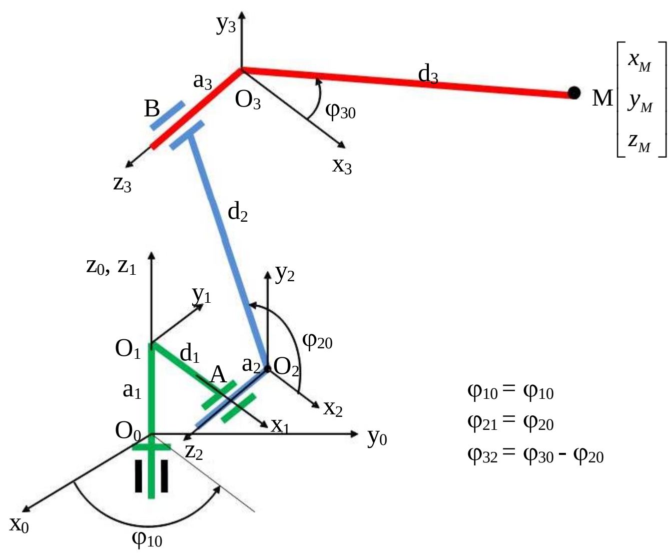

Fig. 16: The spatial basic structure

The proposed study module will be in this topic (the complete, general plan of a structural group, type: 3R dyad, or RRR dyad; see the kinematic diagram of the module in the figures below). It is always known (given) the constant lengths of the two elements of the module: l2 and l3, the positions of the outer coupling, of input *B* (x_B, y_B, z_B), in our case, with plane treatment *B* (x_B, yB). In direct kinematics, the position angles φ_2 and φ_3 are known and the positions of the point (outer coupling) *D*, i.e., (x_D, y_D), are known. In inverse kinematics (our theme), the positions of the D -defector, that is, x_D, y_D, are known, imposed (given) and the position angles φ_2 and φ_3 are demanded (determined) (Fig. 17, 14).

For the articulated quadrilateral mechanism (Fig. 15), one know φ_1 și ω_1 (with that one determines the *B* positions (x_B, y_B), velocities ($\dot{x}_B$, $\dot{y}_B$) and accelerations ($\ddot{x}_B$, $\ddot{y}_B$); and the same parameters for the point *D*: positions (x_D, y_D), velocities ($\dot{x}_D$, $\dot{y}_D$) and accelerations ($\ddot{x}_D$, $\ddot{y}_D$). One has finished with the considered (known) input data of the module and then the inverse kinematics are requested, first of all, the module positions: φ_2, φ_3 and the the angular velocities: ω_2, ω_3 and accelerations: ε_2, ε_3.

In other words, for the inverse kinematics of the module (at which we know the constant lengths of the two elements, 2 and 3, that is l2 and l3, but also the positions, speeds and accelerations of the inputs, couples and or external points, *B* and *D*: x_B, y_B, $\dot{x}_B$, $\dot{y}_B$, $\ddot{x}_B$, $\ddot{y}_B$, x_D, y_D, $\dot{x}_D$, $\dot{y}_D$, $\ddot{x}_D$, $\ddot{y}_D$) it is required to determine the position angles of the two elements, 2 and 3 and their derivatives: φ_2, φ_3, ω_2, ω_3, ε_2, ε_3.

The computational relationships used are those of the relational system 1:

$$\begin{cases}
l_1 = 0.1[m];\ \ l_2 = 0.3[m];\ \ l_3 = 0.2[m];\ \ x_D \equiv l_0 = 0.254[m]; \\
y_D = 0;\ \ \begin{cases} x_B = l_1 \cdot \cos\varphi_1 \\ y_B = l_1 \cdot \sin\varphi_1 \end{cases} \\
\begin{cases} \dot{x}_B = -l_1 \cdot \sin\varphi_1 \cdot \omega_1 \\ \dot{y}_B = l_1 \cdot \cos\varphi_1 \cdot \omega_1 \end{cases};\ \begin{cases} \ddot{x}_B = -l_1 \cdot \cos\varphi_1 \cdot \omega_1^2 \\ \ddot{y}_B = -l_1 \cdot \sin\varphi_1 \cdot \omega_1^2 \end{cases};\ \begin{cases} \dot{x}_D = 0 \\ \dot{y}_D = 0 \end{cases};\ \begin{cases} \ddot{x}_D = 0 \\ \ddot{y}_D = 0 \end{cases}; \\
\begin{cases} l^2 = \left(x_D - x_B\right)^2 + \left(y_D - y_B\right)^2 \\ l = \sqrt{\left(x_D - x_B\right)^2 + \left(y_D - y_B\right)^2} \end{cases} \\
\sin\varphi = \dfrac{y_D - y_B}{l};\ \ \cos\varphi = \dfrac{x_D - x_B}{l};\ \ \varphi = semn\left(\sin\varphi\right) \cdot \arccos\left(\cos\varphi\right) \Rightarrow \\
\Rightarrow \varphi = semn\left(\dfrac{y_D - y_B}{l}\right) \cdot \arccos\left(\dfrac{x_D - x_B}{l}\right) \\
\begin{cases} \cos B = \dfrac{l^2 + l_2^2 - l_3^2}{2 \cdot l \cdot l_2} \Rightarrow B = \arccos\left(\cos B\right) = \arccos\left(\dfrac{l^2 + l_2^2 - l_3^2}{2 \cdot l \cdot l_2}\right) \\ \cos D = \dfrac{l^2 + l_3^2 - l_2^2}{2 \cdot l \cdot l_3} \Rightarrow D = \arccos\left(\cos D\right) = \arccos\left(\dfrac{l^2 + l_3^2 - l_2^2}{2 \cdot l \cdot l_3}\right) \end{cases} \\
\Rightarrow \begin{cases} \varphi_2 = \varphi \pm \hat{B} \Rightarrow \varphi_2 = \varphi + \hat{B} \\ \varphi_3 = \varphi \mp \hat{D} \Rightarrow \varphi_3 = \varphi - \hat{D} \end{cases} \\
\omega_2 = \dfrac{\left(\dot{x}_D - \dot{x}_B\right) \cdot \cos\varphi_3 + \left(\dot{y}_D - \dot{y}_B\right) \cdot \sin\varphi_3}{l_2 \cdot \sin\left(\varphi_3 - \varphi_2\right)} = \dfrac{l_1}{l_2} \cdot \dfrac{\sin\left(\varphi_1 - \varphi_3\right)}{\sin\left(\varphi_3 - \varphi_2\right)} \cdot \omega_1 \\
\omega_3 = \dfrac{\left(\dot{x}_D - \dot{x}_B\right) \cdot \cos\varphi_2 + \left(\dot{y}_D - \dot{y}_B\right) \cdot \sin\varphi_2}{l_3 \cdot \sin\left(\varphi_2 - \varphi_3\right)} = \dfrac{l_1}{l_3} \cdot \dfrac{\sin\left(\varphi_1 - \varphi_2\right)}{\sin\left(\varphi_2 - \varphi_3\right)} \cdot \omega_1 \\
\varepsilon_2 = \dfrac{\left(\ddot{x}_D - \ddot{x}_B\right) \cdot \cos\varphi_3 + \left(\ddot{y}_D - \ddot{y}_B\right) \cdot \sin\varphi_3 + l_2 \cdot \omega_2^2 \cdot \cos\left(\varphi_3 - \varphi_2\right) + l_3 \cdot \omega_3^2}{l_2 \cdot \sin\left(\varphi_3 - \varphi_2\right)} \\
\varepsilon_3 = \dfrac{\left(\ddot{x}_D - \ddot{x}_B\right) \cdot \cos\varphi_2 + \left(\ddot{y}_D - \ddot{y}_B\right) \cdot \sin\varphi_2 + l_2 \cdot \omega_2^2 + l_3 \cdot \omega_3^2 \cdot \cos\left(\varphi_2 - \varphi_3\right)}{l_3 \cdot \sin\left(\varphi_2 - \varphi_3\right)}
\end{cases} \quad (1)$$

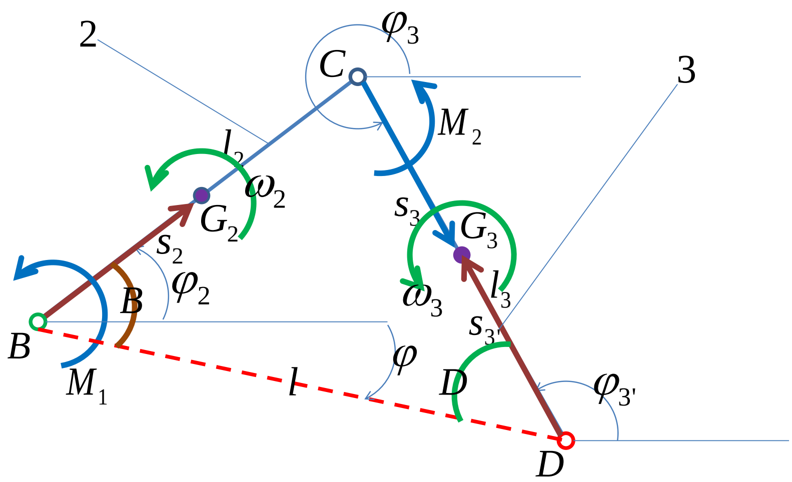

Fig. 17: The planar basic structure

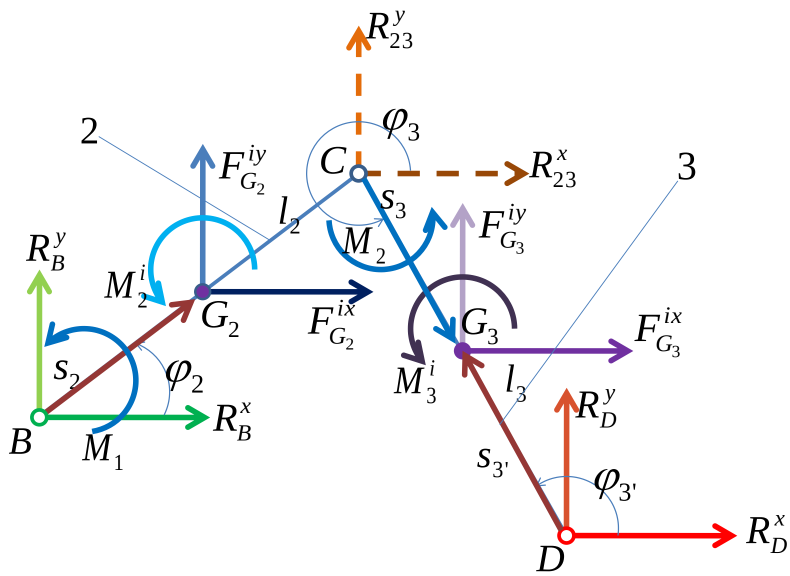

Fig. 18: Forces of the base planar system

The kinetic statics (the study of forces) of a 3R dyad (Mechatronic Module 2R) is of dual importance, this structural group being present in many mechanisms, but also in the composition of all the current major anthropomorphic serial robots (Fig. 18).

One know:

$$l_2, l_3, s_2, s_3, x_B, y_B, \dot{x}_B, \dot{y}_B, \ddot{x}_B, \ddot{y}_B, x_D, y_D, \dot{x}_D, \dot{y}_D,$$
$$\ddot{x}_D, \ddot{y}_D, \phi_2, \phi_3, \omega_2, \omega_3, \varepsilon_2, \varepsilon_3, m_2, m_3, J_{G_2}, J_{G_3}, M_1, M_2$$

The reactions from the couples must be determined:

$$R_B^x \equiv R_{12}^x, R_B^y \equiv R_{12}^y, R_D^x \equiv R_{03}^x, R_D^y \equiv R_{03}^y, R_{23}^x \equiv R_C^x, R_{23}^y \equiv R_C^y$$

The torsion of the inertial forces is calculated with the relations (2), for elements 2 and 3. The positions, speeds and accelerations of the centers of weight are also needed:

$$\begin{cases} \begin{cases} F_{G_2}^{ix} = -m_2 \cdot \ddot{x}_{G_2} \\ F_{G_2}^{iy} = -m_2 \cdot \ddot{y}_{G_2} \\ M_2^i = -J_{G_2} \cdot \varepsilon_2 \end{cases} & \begin{cases} F_{G_3}^{ix} = -m_3 \cdot \ddot{x}_{G_3} \\ F_{G_3}^{iy} = -m_3 \cdot \ddot{y}_{G_3} \\ M_3^i = -J_{G_3} \cdot \varepsilon_3 \end{cases} \end{cases} \quad (2)$$

The accelerations of the mass centers are determined with the relations 3:

$$\begin{cases} \begin{cases} x_{G_2} = x_B + s_2 \cdot \cos\varphi_2 \\ y_{G_2} = y_B + s_2 \cdot \sin\varphi_2 \end{cases} \begin{cases} \dot{x}_{G_2} = \dot{x}_B - s_2 \cdot \sin\varphi_2 \cdot \omega_2 \\ \dot{y}_{G_2} = \dot{y}_B + s_2 \cdot \cos\varphi_2 \cdot \omega_2 \end{cases} \\ \begin{cases} \ddot{x}_{G_2} = \ddot{x}_B - s_2 \cdot \cos\varphi_2 \cdot \omega_2^2 - s_2 \cdot \sin\varphi_2 \cdot \varepsilon_2 \\ \ddot{y}_{G_2} = \ddot{y}_B - s_2 \cdot \sin\varphi_2 \cdot \omega_2^2 + s_2 \cdot \cos\varphi_2 \cdot \varepsilon_2 \end{cases} \\ \\ \begin{cases} x_{G_3} = x_B + l_2 \cdot \cos\varphi_2 + s_3 \cdot \cos\varphi_3 \\ y_{G_3} = y_B + l_2 \cdot \sin\varphi_2 + s_3 \cdot \sin\varphi_3 \end{cases} \\ \begin{cases} \dot{x}_{G_3} = \dot{x}_B - l_2 \cdot \sin\varphi_2 \cdot \omega_2 - s_3 \cdot \sin\varphi_3 \cdot \omega_3 \\ \dot{y}_{G_3} = \dot{y}_B + l_2 \cdot \cos\varphi_2 \cdot \omega_2 + s_3 \cdot \cos\varphi_3 \cdot \omega_3 \end{cases} \\ \begin{cases} \ddot{x}_{G_3} = \ddot{x}_B - l_2 \cdot \cos\varphi_2 \cdot \omega_2^2 - l_2 \cdot \sin\varphi_2 \cdot \varepsilon_2 \\ -s_3 \cdot \cos\varphi_3 \cdot \omega_3^2 - s_3 \cdot \sin\varphi_3 \cdot \varepsilon_3 \\ \ddot{y}_{G_3} = \ddot{y}_B - l_2 \cdot \sin\varphi_2 \cdot \omega_2^2 + l_2 \cdot \cos\varphi_2 \cdot \varepsilon_2 \\ -s_3 \cdot \sin\varphi_3 \cdot \omega_3^2 + s_3 \cdot \cos\varphi_3 \cdot \varepsilon_3 \end{cases} \end{cases} \quad (3)$$

The forces in the system are determined with the help of relations 4-5:

$$\begin{cases} \sum M_C^{(2)} = 0 \Rightarrow R_B^x \cdot (y_C - y_B) - R_B^y \cdot (x_C - x_B) + M_1 + F_{G_2}^{ix} \cdot (y_C - y_{G_2}) - F_{G_2}^{iy} \cdot (x_C - x_{G_2}) + M_2^i = 0 \\ \sum M_D^{(2,3)} = 0 \Rightarrow R_B^x \cdot (y_D - y_B) - R_B^y \cdot (x_D - x_B) + M_1 + F_{G_2}^{ix} \cdot (y_D - y_{G_2}) - F_{G_2}^{iy} \cdot (x_D - x_{G_2}) + M_2^i \\ +M_2 + F_{G_3}^{ix} \cdot (y_D - y_{G_3}) - F_{G_3}^{iy} \cdot (x_D - x_{G_3}) + M_3^i = 0 \\ \begin{cases} (y_C - y_B) \cdot R_B^x - (x_C - x_B) \cdot R_B^y = -M_1 - F_{G_2}^{ix} \cdot (y_C - y_{G_2}) + F_{G_2}^{iy} \cdot (x_C - x_{G_2}) - M_2^i \\ (y_D - y_B) \cdot R_B^x - (x_D - x_B) \cdot R_B^y = -M_1 - F_{G_2}^{ix} \cdot (y_D - y_{G_2}) + F_{G_2}^{iy} \cdot (x_D - x_{G_2}) - M_2^i \\ -M_2 - F_{G_3}^{ix} \cdot (y_D - y_{G_3}) + F_{G_3}^{iy} \cdot (x_D - x_{G_3}) - M_3^i \end{cases} \\ \begin{cases} a_{11} \cdot R_B^x + a_{12} \cdot R_B^y = a_1 \\ a_{21} \cdot R_B^x + a_{22} \cdot R_B^y = a_2 \end{cases} \\ \Rightarrow \begin{cases} a_{11} = y_C - y_B; \;\; a_{12} = -(x_C - x_B); \;\; a_1 = -M_1 - F_{G_2}^{ix} \cdot (y_C - y_{G_2}) + F_{G_2}^{iy} \cdot (x_C - x_{G_2}) - M_2^i \\ a_{21} = y_D - y_B; \;\; a_{22} = -(x_D - x_B); \\ a_2 = -M_1 - F_{G_2}^{ix} \cdot (y_D - y_{G_2}) + F_{G_2}^{iy} \cdot (x_D - x_{G_2}) - M_2^i - M_2 - F_{G_3}^{ix} \cdot (y_D - y_{G_3}) + F_{G_3}^{iy} \cdot (x_D - x_{G_3}) - M_3^i \end{cases} \\ \Delta = \begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} = a_{11} \cdot a_{22} - a_{12} \cdot a_{21}; \;\; \Delta_x = \begin{vmatrix} a_1 & a_{12} \\ a_2 & a_{22} \end{vmatrix} = a_1 \cdot a_{22} - a_{12} \cdot a_2; \;\; \Delta_y = \begin{vmatrix} a_{11} & a_1 \\ a_{21} & a_2 \end{vmatrix} = a_{11} \cdot a_2 - a_1 \cdot a_{21} \\ R_B^x = \frac{\Delta_x}{\Delta}; \quad R_B^y = \frac{\Delta_y}{\Delta} \end{cases} \quad (4)$$

$$\begin{cases} \sum F_x^{(2,3)} = 0 \Rightarrow R_D^x + R_B^x + F_{G_2}^{ix} + F_{G_3}^{ix} = 0 \Rightarrow R_D^x = -R_B^x - F_{G_2}^{ix} - F_{G_3}^{ix} \\ \sum F_y^{(2,3)} = 0 \Rightarrow R_D^y + R_B^y + F_{G_2}^{iy} + F_{G_3}^{iy} = 0 \Rightarrow R_D^y = -R_B^y - F_{G_2}^{iy} - F_{G_3}^{iy} \\ \\ \sum F_x^{(3)} = 0 \Rightarrow R_{23}^x + F_{G_3}^{ix} + R_D^x = 0 \Rightarrow R_{23}^x = -F_{G_3}^{ix} - R_D^x \\ \sum F_y^{(3)} = 0 \Rightarrow R_{23}^y + F_{G_3}^{iy} + R_D^y = 0 \Rightarrow R_{23}^y = -F_{G_3}^{iy} - R_D^y \end{cases} \quad (5)$$

Results and Discussion

The variation of the angles FI2 and FI3 depending on the angle Fi1 is simulated in the diagrams in Fig. 19.

The variation of the two angular speeds w2 and w3 depending on the input angle FI1 can be seen in Fig. 20.

The variation of the two angular accelerations Eps and Eps3 depending on the input angle FI1 can be seen in Fig. 21.

The coupling forces, classically called reactions, can be traced in Fig. 22, also depending on the angle of entry FI1.

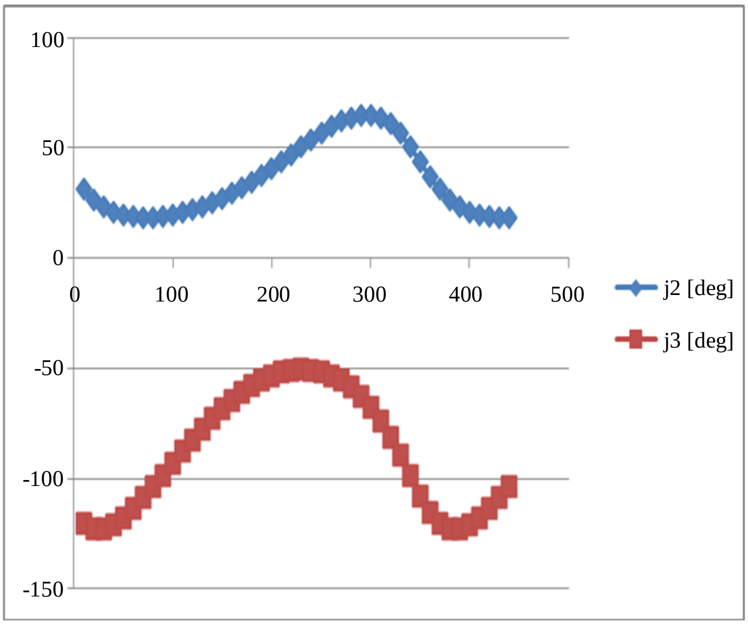

Fig. 19: The variation of the angles FI2 and FI3 depending on the angle Fi1; l1 = 0.1 [m]

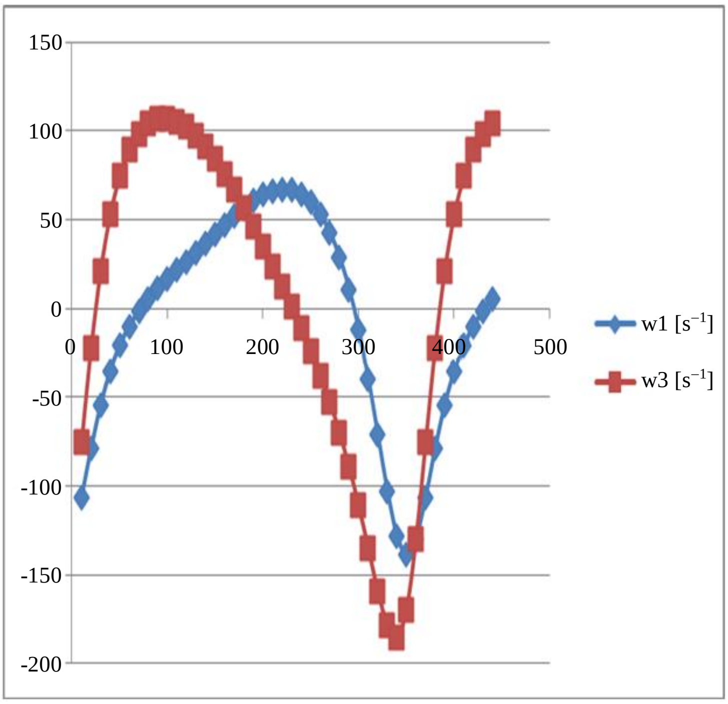

Fig. 20: The variation of the two angular speeds w2 and w3 depending on the input angle FI1; w1 = 200 [rpm]; l1 = 0.1 [m]

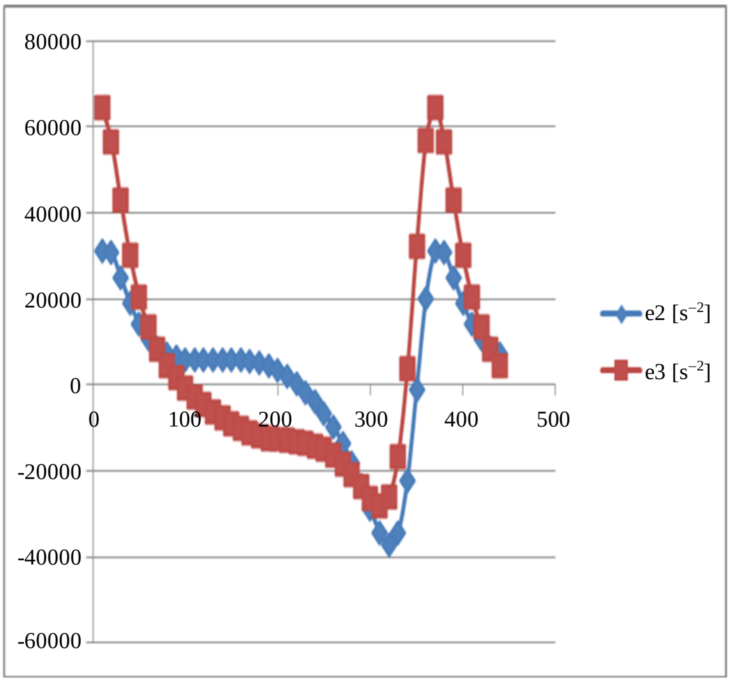

Fig. 21: The variation of the two angular accelerations Eps and Eps3 depending on the input angle FI1; w1 = 200 [rpm]; l1 = 0.1 [m]

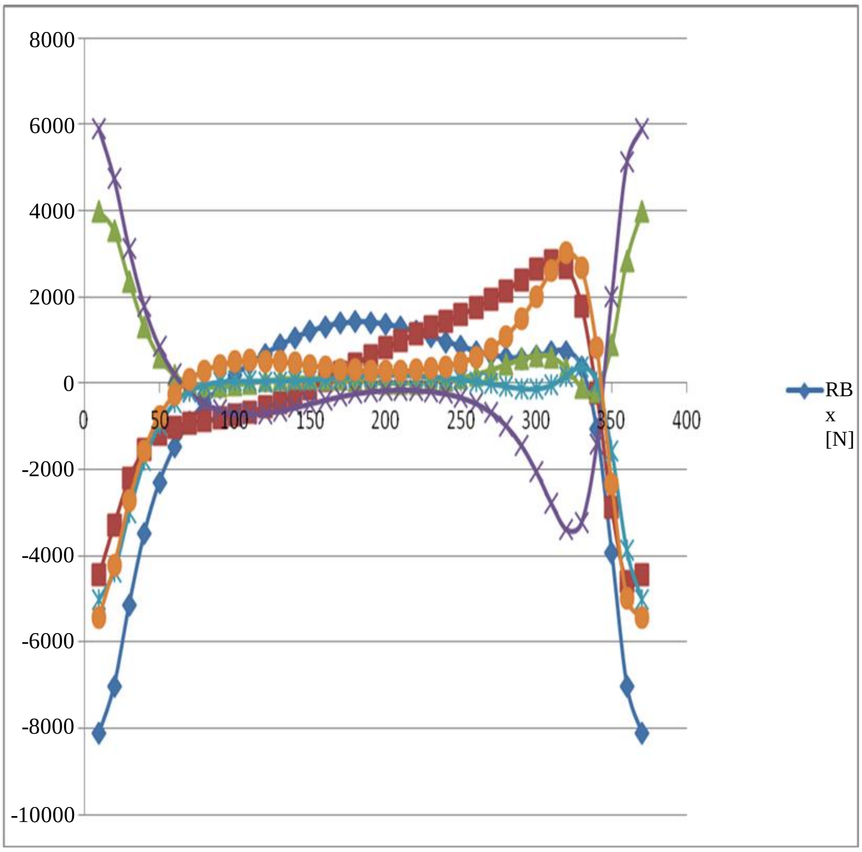

Fig. 22: The coupling forces, classically called reactions, can be traced in Fig. 22; w1 = 200 [rpm]; l1 = 0.1[m]

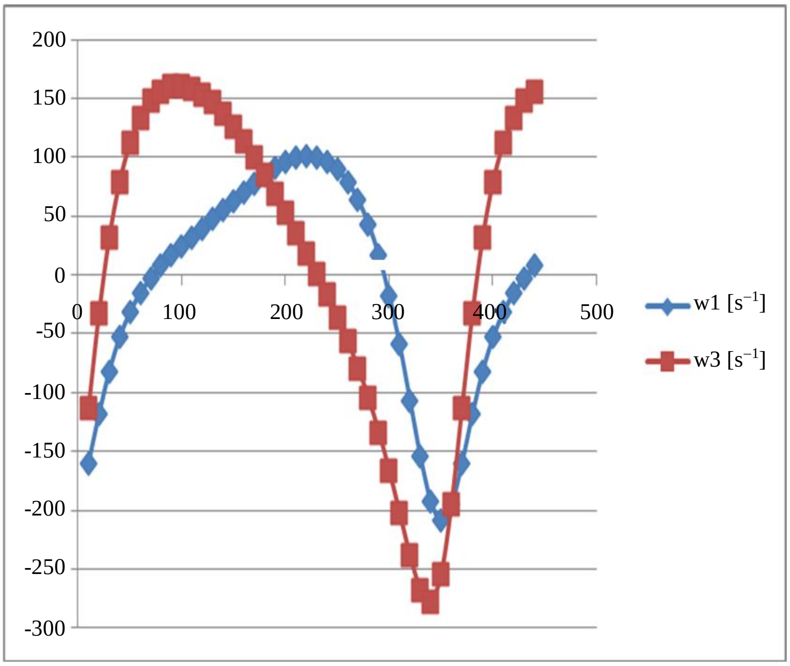

Fig. 23: The variation of the two angular speeds w2 and w3 depending on the input angle FI1; w1 = 300 [rpm]

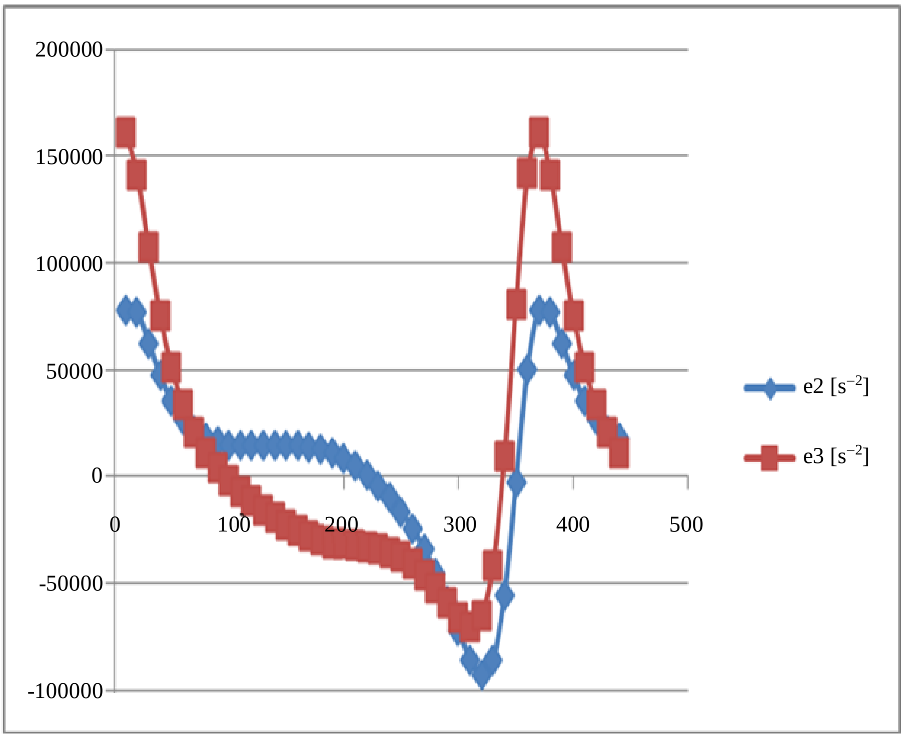

Fig. 24: The variation of the two angular accelerations Eps and Eps3 depending on the input angle FI1; w1=300 [rpm]

All calculations were made for the angular velocity of input w1 = 200 [rot/min], but if its value increases to 300 [rot/min] the diagrams in Fig. 23-25 will be obtained.

If we decrease the length of the crank used 10 times, l1, we will have the following three diagrams (Fig. 26-28) still using the first value of the crank angular speed, w1 = 200 [rpm].

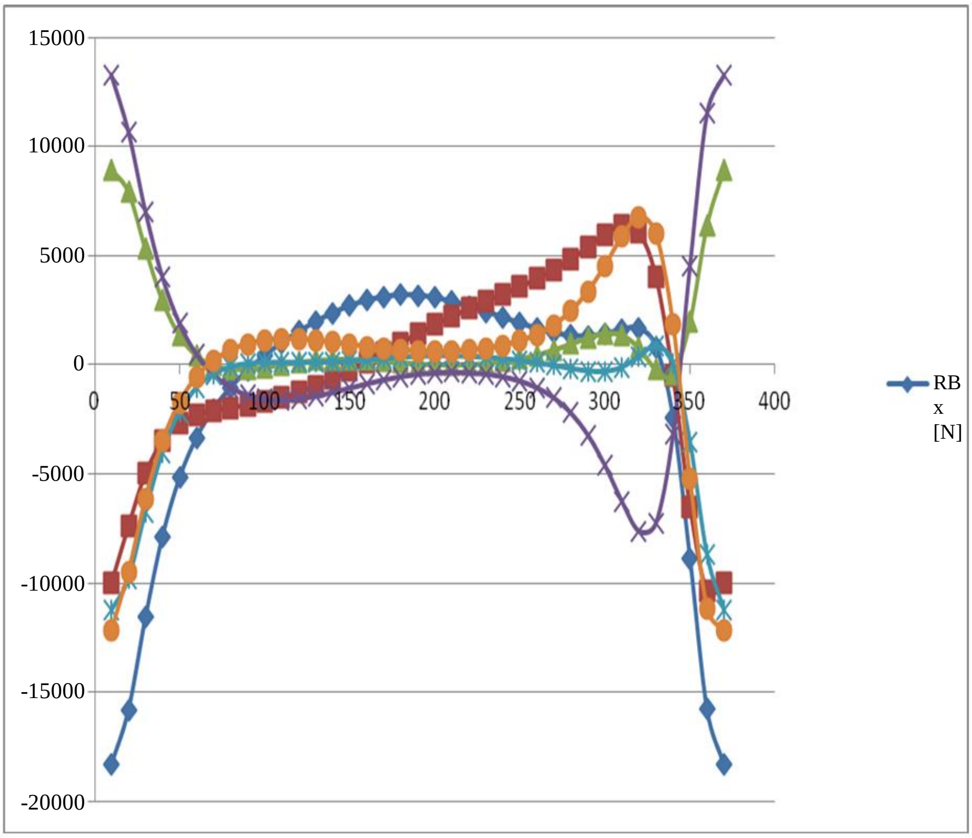

Fig. 25: The coupling forces, classically called reactions, can be traced in Fig. 22; w1=300 [rpm]

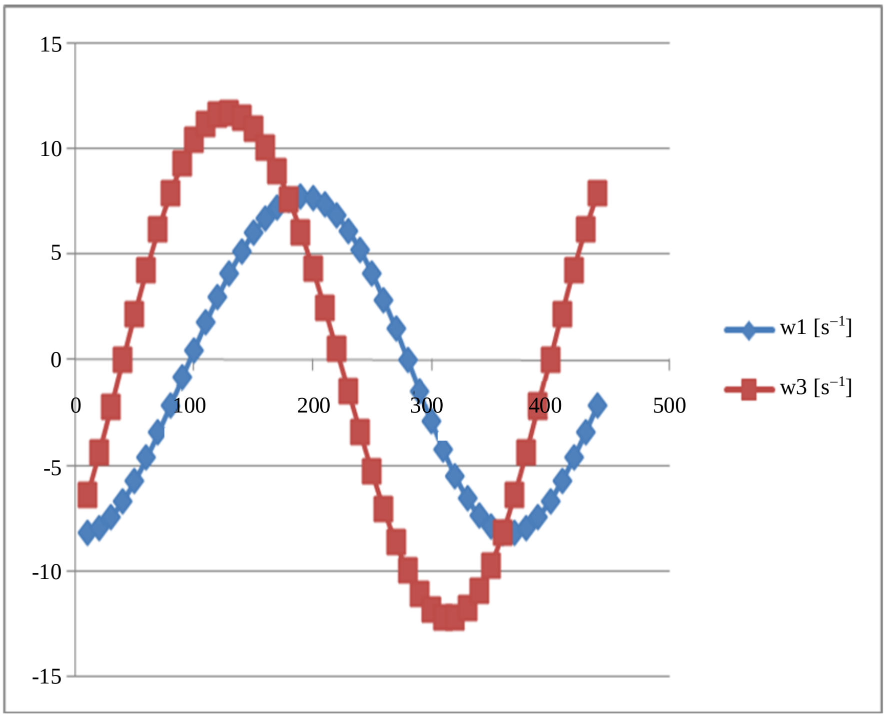

Fig. 26: The variation of the two angular speeds w2 and w3 depending on the input angle FI1; w1 = 200 [rpm]; l1 = 0.01 [m]

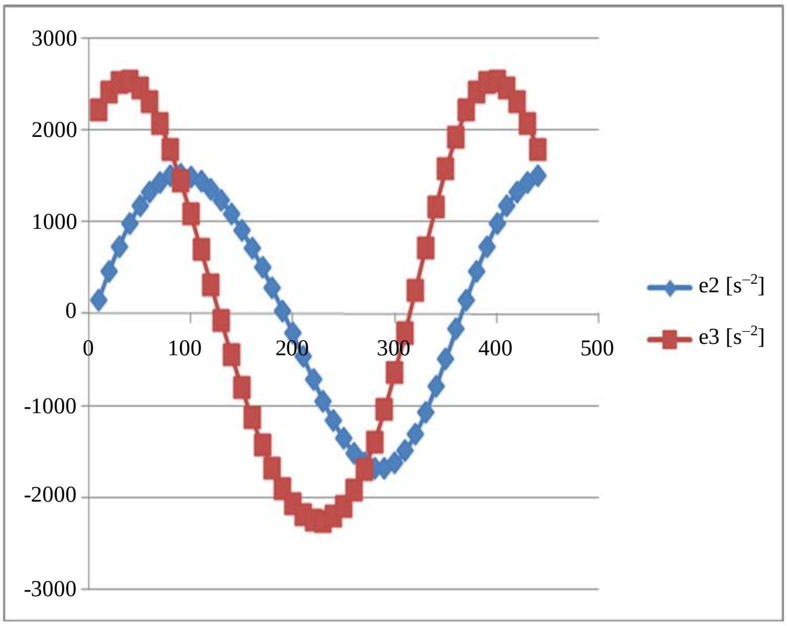

Fig. 27: The variation of the two angular accelerations Eps and Eps3 depending on the input angle FI1; w1 = 200 [rpm]; l1 = 0.01 [m]

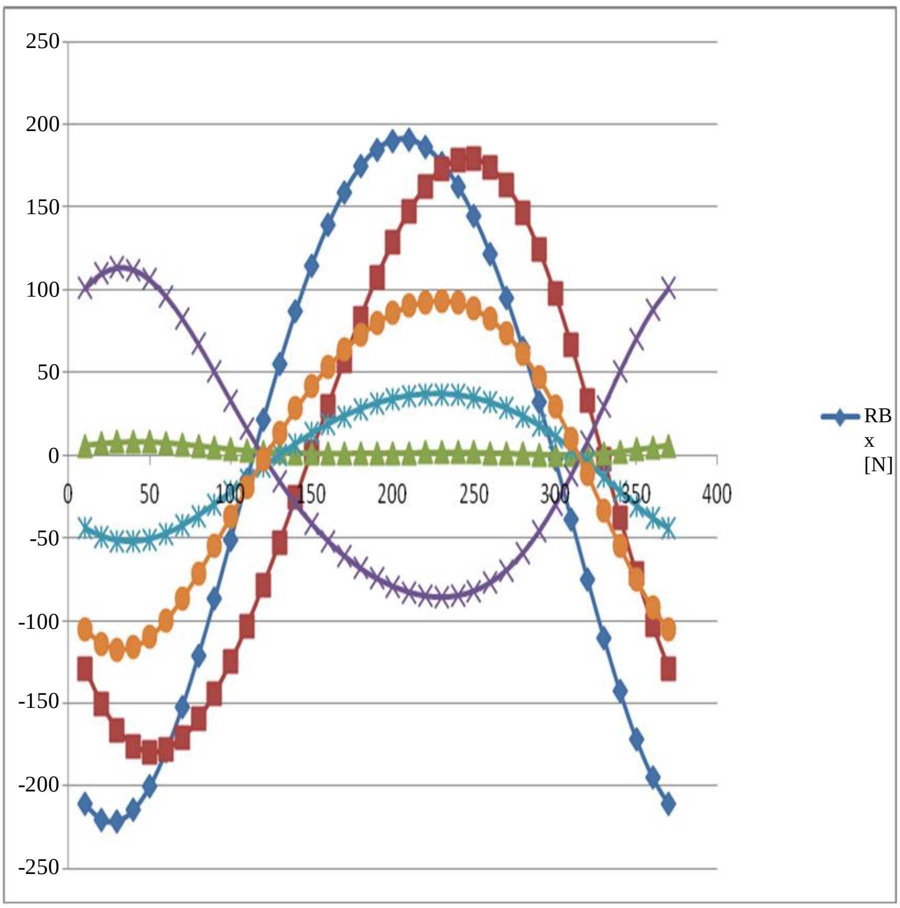

Fig. 28: The coupling forces, classically called reactions, can be traced in Fig. 22; w1 = 200 [rpm]; l1 = 0.01[m]

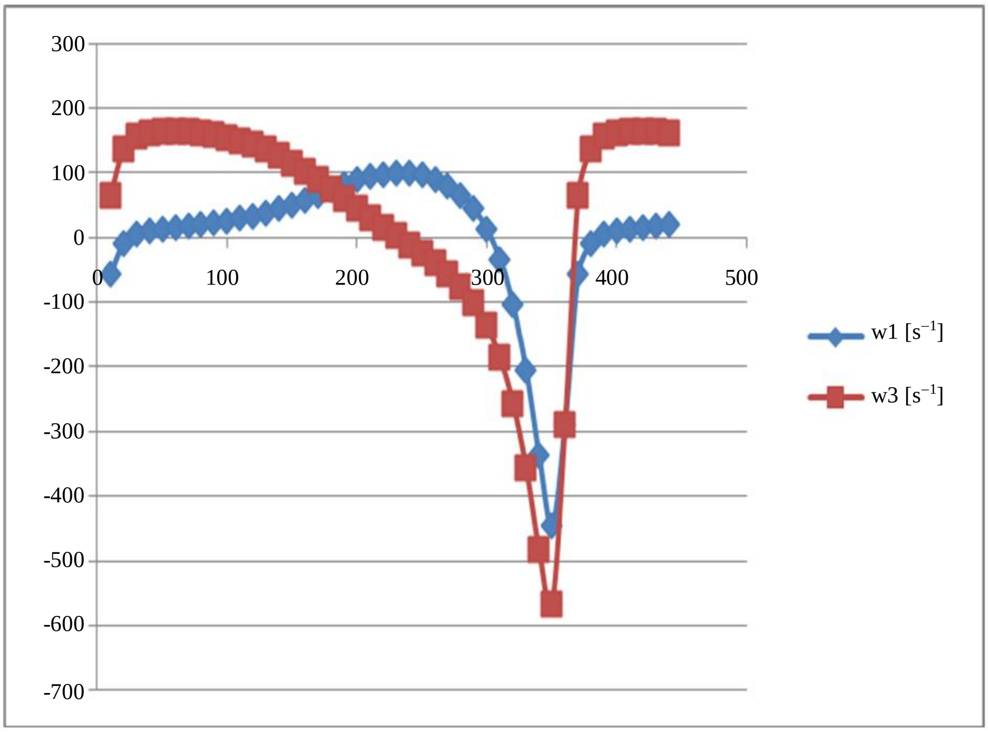

Fig. 29: The variation of the two angular speeds w2 and w3 depending on the input angle FI1; w1=200 [rpm]; l1=0.15 [m]

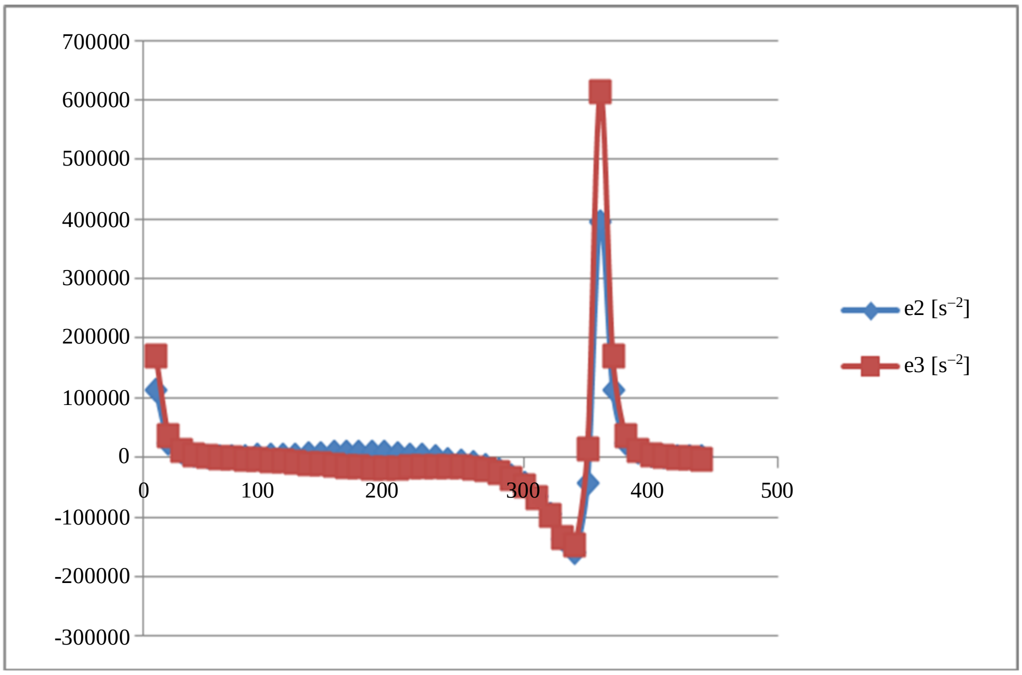

Fig. 30: The variation of the two angular accelerations Eps and Eps3 depending on the input angle FI1; w1=200 [rpm]; l1=0.15 [m]

However, if we increase the initial crank by only 50% instead of decreasing it, the vibrations in the mode increase a lot and the dynamics worsen, the more the longer the crank used, the forces greatly increased (Fig. 29-31).

Then we resume the problem with all the initial data but we change between them the lengths of elements 2 and 3 and we will obtain the diagrams in Fig. 32-34.

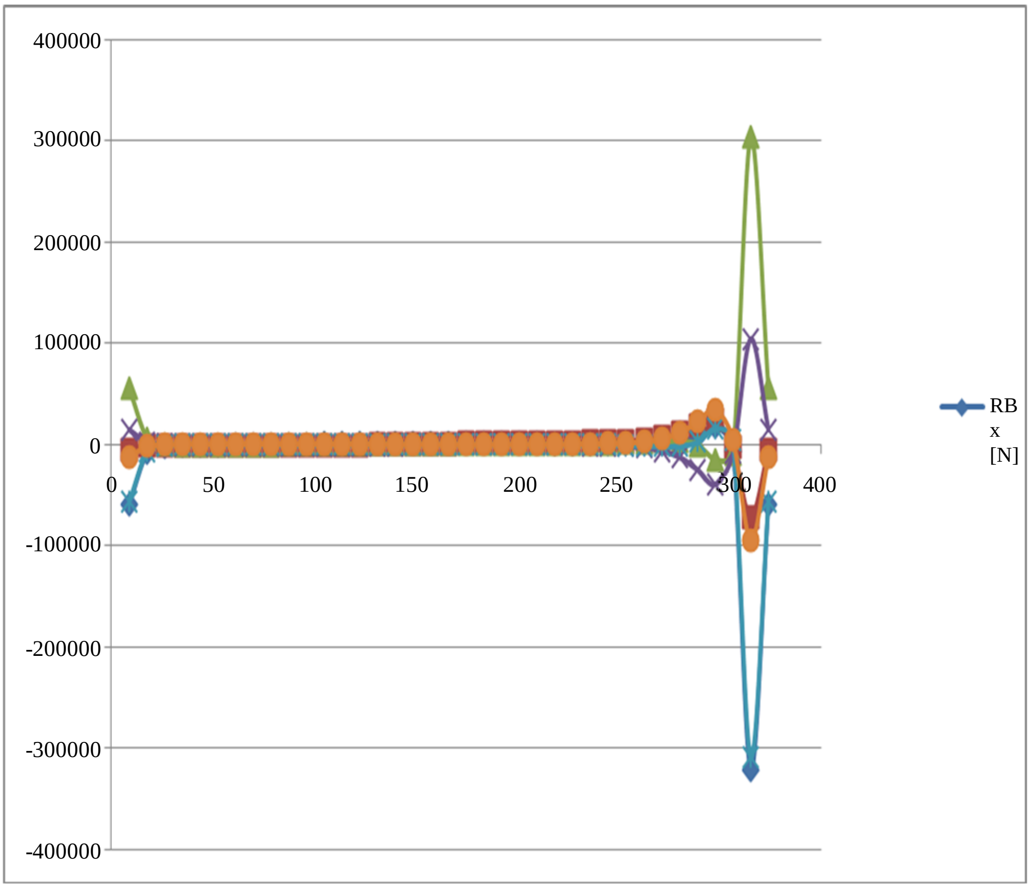

Fig. 31: The coupling forces, classically called reactions, can be traced in Fig. 22; w1=200 [rpm]; l1=0.15[m]

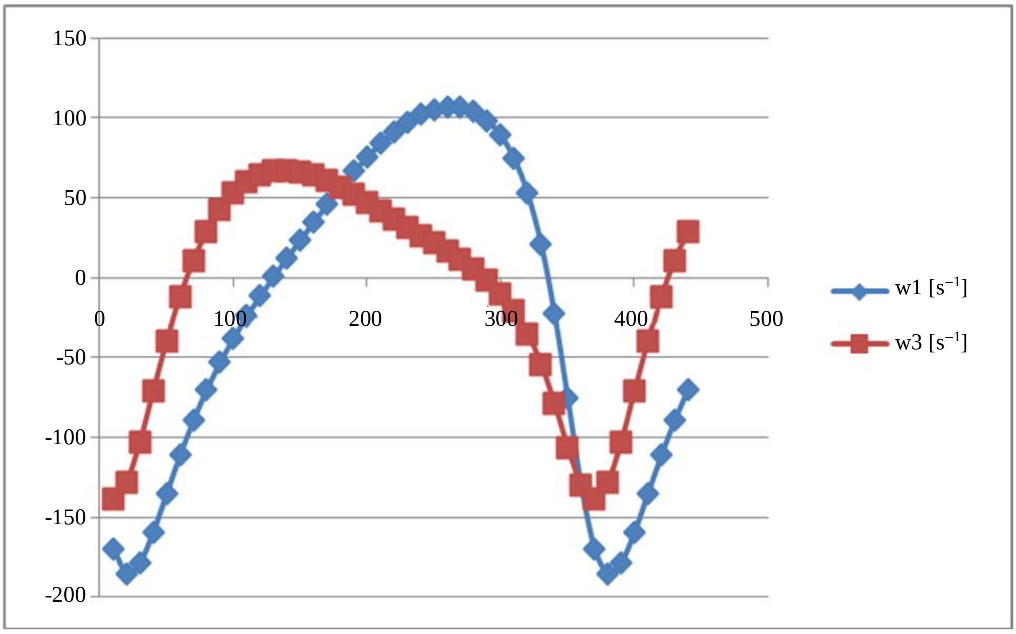

Fig. 32: The variation of the two angular speeds w2 and w3 depending on the input angle FI1; w1=200 [rpm]; l1=0.1 [m]; l2<->l3

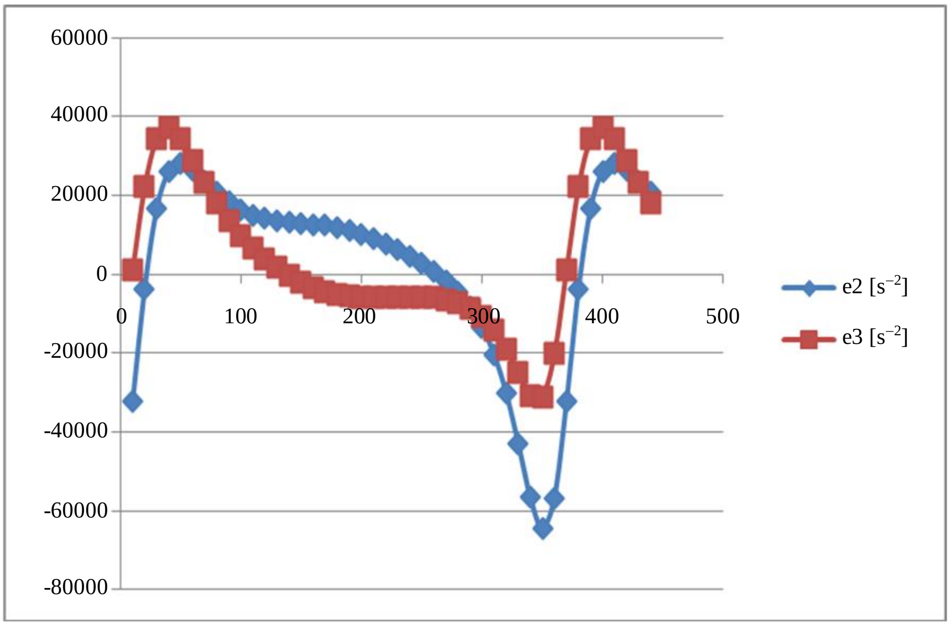

Fig. 33: The variation of the two angular accelerations Eps and Eps3 depending on the input angle FI1; w1=200 [rpm]; l1=0.1 [m]; l2<->l3

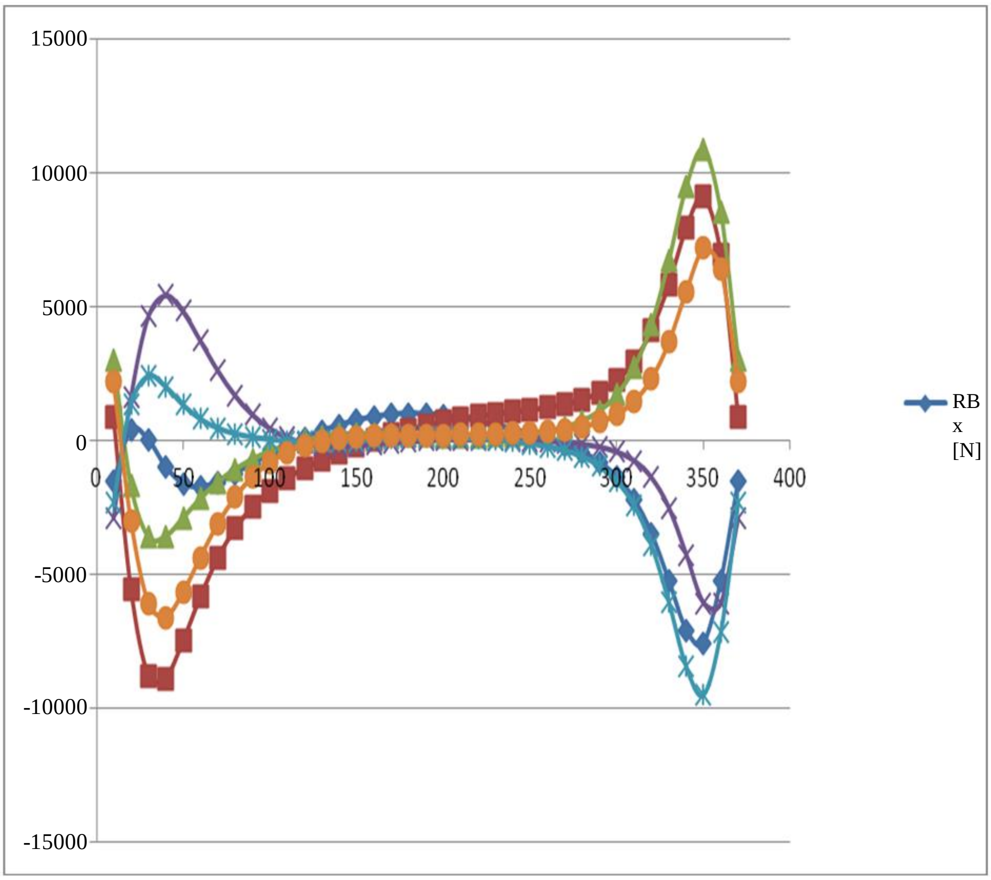

Fig. 34: The coupling forces, classically called reactions, can be traced in Fig. 22; w1=200 [rpm]; l1=0.1[m]; l2<->l3

Conclusion

The basic structure of the anthropomorphic robots used today massively in 80-90% cases from the industrial robots will be presented briefly, with the highlighting of an original method for determining the kinematics of the basic 3R module and with highlighting the forces at the basic structure set in the discussion. Some representative examples of calculation will be remembered as results. The paper is a basic one in the field and performs a recapitulation of how the basic anthropomorphic structures 3R are analyzed or designed correctly and quickly.

When we want to analyze the robot that we will implement, a prior engineering study is needed, which will clearly indicate what type of robot we will buy, but if the robot has already been purchased, an implementation study will be necessary to fix the software. work, the robot software at optimal values. If we have the pleasure to design such a robotic system ourselves then it will be much easier to perform the calculations necessary to achieve an optimal assembly that corresponds to the majority of the basic requirements of the future period of system operation as a whole.

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3. Contract research. GR 69/10.05.2007: NURC in 2762; theme 8: Dynamic analysis of mechanisms and manipulators with bars and gears.
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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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