American Journal of Engineering and Applied Sciences

Original Research Paper

Kinematics of a Mechanism with a Triad

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Article history
Received: 25-02-2018
Revised: 26-02-2018
Accepted: 01-03-2018

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Abstract: The Assuric Structural Groups are the most well-known classification and modulation used in machine and machine theory, and even though other modular classifications adapted to robots have emerged today, they still remain a reference classification in industrial mechanics and engineering. Diada in the mechanics can be studied similarly to the diode in the electronics, the triad is studied in the theory of machine and robot mechanisms similar to triode (or transistor) study in electronics. Further, the theory of the mechanisms is studying: tetrad, pentad ... but it cannot go further than for a 12th-order structural group because the efficiency of mechanisms using such very large groups is very small and such a mechanism can be blocked in operation. If the similarity between the mechanisms and the electronics is correct up to the 5-6th class, the larger ones are of no use, the advantages of the electronics being that it can also function in the large or very large group with high yields, without blockages, which is why the integrated circuits and electronic chips were born. The present work is intended presenting a triad kinematics general used only with the kinematic couplings rotational (C5), because such approaches are rare in the area, although triad is a structured group Assuric often used. The calculation method presented is an analytical one.

Keywords: Mechanisms, Robots, Mechatronics, Structural Groups, Dyad, Triad, Kinematics, Triad Kinematics, An Analytical Method

Introduction

In machines, mechanisms and robots theory, structural or modular groups are often used to ease calculations of various mechanisms used on machines and industrial robots.

The most well-known structural classification in groups is the Assuric one which use dyads and triads...

A less studied Assuric group is the triad, which is why the present paper wants to present the analytical kinematics of this third-class structural group, determined by an original method.

Structural groups have been thoroughly analyzed in some specialized papers (Pelecudi, 1967; Antonescu, 2000; Comănescu *et al*., 2010), but not from an analytical point of view, but more structurally and graphically.

The Assuric Structural Groups are the most well-known classification and modulation used in machine and machine theory, and even though other modular classifications adapted to robots have emerged today, they still remain a reference classification in industrial mechanics and engineering.

Dyad in the mechanics can be studied similarly to the diode in the electronics, the triad is studied in the theory of machine and robot mechanisms similar to triode (or transistor) study in electronics. Further, the theory of the mechanisms is studying: tetrad, pentad ... but it cannot go further than for a 12th-order structural group because the efficiency of mechanisms using such very large groups is very small and such a mechanism can be blocked in operation. If the similarity between the mechanisms and the electronics is correct up to the 5-6th class, the larger ones are of no use, the advantages of the electronics being that it can also function in the large or very large group with high yields, without blockages, which is why the integrated circuits and electronic chips were born.

Science Publications

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The present work is intended presenting a triad kinematics general used only with the kinematic couplings rotational (C5), because such approaches are rare in the area, although triad is a structured group Assuric often used. The calculation method presented is an analytical one (Pelecudi, 1967; Antonescu, 2000; Comănescu *et al.*, 2010; 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; 2016a-e; 2017a-ae; Petrescu and Calautit, 2016a-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 kinematic scheme of a 6R triad can be seen in Fig. 1.

The kinematic equations of positions are written for two independent contours in the form of the system (1).

Although a system of four equations with four unknowns results, solving the system is more difficult because the equations are transcendental.

$$\begin{cases}\begin{cases}x_B + l_2\cdot\cos\varphi_2 = x_C + l_3\cdot\cos\varphi_3 + g\cdot\cos(\varphi_5+\alpha)\\ y_B + l_2\cdot\sin\varphi_2 = y_C + l_3\cdot\sin\varphi_3 + g\cdot\sin(\varphi_5+\alpha)\end{cases}\\ \\ \begin{cases}x_C + l_3\cdot\cos\varphi_3 + e\cdot\cos\varphi_5 = x_D + l_4\cdot\cos\varphi_4\\ y_C + l_3\cdot\sin\varphi_3 + e\cdot\sin\varphi_5 = y_D + l_4\cdot\sin\varphi_4\end{cases}\end{cases} \tag{1}$$

Write the system (1) in form (2) and lift each equation to square, then add the first two and the last two to eliminate the two unknown (φ_2 and φ_4). We obtain the new system (3) of two equations with two unknowns which are arranged successively in the forms (4), (5) and (6).

$$\begin{cases}\left.\begin{cases}l_2\cdot\cos\varphi_2 = x_C - x_B + l_3\cdot\cos\varphi_3 + g\cdot\cos(\varphi_5+\alpha)\,|\,\hat{}2\\ l_2\cdot\sin\varphi_2 = y_C - y_B + l_3\cdot\sin\varphi_3 + g\cdot\sin(\varphi_5+\alpha)\,|\,\hat{}2\end{cases}\right.\Rightarrow I\\ \\ \left.\begin{cases}l_4\cdot\cos\varphi_4 = x_C - x_D + l_3\cdot\cos\varphi_3 + e\cdot\cos\varphi_5\,|\,\hat{}2\\ l_4\cdot\sin\varphi_4 = y_C - y_D + l_3\cdot\sin\varphi_3 + e\cdot\sin\varphi_5\,|\,\hat{}2\end{cases}\right.\Rightarrow II\end{cases} \tag{2}$$

$$\begin{cases}I:\ l_2^2 = \left[(x_C-x_B) + l_3\cdot\cos\varphi_3 + g\cdot\cos(\varphi_5+\alpha)\right]^2 +\\ +\left[(y_C-y_B) + l_3\cdot\sin\varphi_3 + g\cdot\sin(\varphi_5+\alpha)\right]^2\\ \\ II:\ l_4^2 = \left[(x_C-x_D) + l_3\cdot\cos\varphi_3 + e\cdot\cos\varphi_5\right]^2 +\\ +\left[(y_C-y_D) + l_3\cdot\sin\varphi_3 + e\cdot\sin\varphi_5\right]^2\end{cases} \tag{3}$$

$$\begin{cases}l_2^2 = (x_C-x_B)^2 + (y_C-y_B)^2 + l_3^2 + g^2 +\\ 2\cdot l_3\cdot(x_C-x_B)\cdot\cos\varphi_3 + 2\cdot l_3\cdot(y_C-y_B)\cdot\sin\varphi_3\\ +2\cdot g\cdot(x_C-x_B)\cdot\cos(\varphi_5+\alpha) + 2\cdot g\cdot(y_C-y_B)\cdot\\ \sin(\varphi_5+\alpha) + 2\cdot g\cdot l_3\cdot\cos(\varphi_5+\alpha-\varphi_3)\\ \\ l_4^2 = (x_C-x_D)^2 + (y_C-y_D)^2 + l_3^2 + e^2 +\\ 2\cdot l_3\cdot(x_C-x_D)\cdot\cos\varphi_3 + 2\cdot l_3\cdot(y_C-y_D)\cdot\sin\varphi_3\\ +2\cdot e\cdot(x_C-x_D)\cdot\cos\varphi_5 +\\ +2\cdot e\cdot(y_C-y_D)\cdot\sin\varphi_5 + 2\cdot e\cdot l_3\cdot\cos(\varphi_5-\varphi_3)\end{cases} \tag{4}$$

$$\begin{cases}l_2^2 = (x_C-x_B)^2 + (y_C-y_B)^2 + l_3^2 + g^2 +\\ 2\cdot l_3\cdot(x_C-x_B)\cdot\cos\varphi_3 + 2\cdot l_3\cdot(y_C-y_B)\cdot\sin\varphi_3\\ +2\cdot g\cdot(x_C-x_B)\cdot\cos\alpha\cdot\cos\varphi_5 -\\ -2\cdot g\cdot(x_C-x_B)\cdot\sin\alpha\cdot\sin\varphi_5 +\\ 2\cdot g\cdot(y_C-y_B)\cdot\sin\alpha\cdot\cos\varphi_5 +\\ 2\cdot g\cdot(y_C-y_B)\cdot\cos\alpha\cdot\sin\varphi_5 +\\ 2\cdot g\cdot l_3\cdot\cos\alpha\cdot\cos(\varphi_5-\varphi_3) -\\ 2\cdot g\cdot l_3\cdot\sin\alpha\cdot\sin(\varphi_5-\varphi_3)\\ \\ l_4^2 = (x_C-x_D)^2 + (y_C-y_D)^2 + l_3^2 + e^2 +\\ 2\cdot l_3\cdot(x_C-x_D)\cdot\cos\varphi_3 + 2\cdot l_3\cdot(y_C-y_D)\cdot\sin\varphi_3\\ +2\cdot e\cdot(x_C-x_D)\cdot\cos\varphi_5 +\\ +2\cdot e\cdot(y_C-y_D)\cdot\sin\varphi_5 + 2\cdot e\cdot l_3\cdot\cos(\varphi_5-\varphi_3)\end{cases} \tag{5}$$

$$\begin{cases}l_2^2 = (x_C-x_B)^2 + (y_C-y_B)^2 + l_3^2 + g^2 +\\ 2\cdot l_3\cdot(x_C-x_B)\cdot\cos\varphi_3 + 2\cdot l_3\cdot(y_C-y_B)\cdot\sin\varphi_3 +\\ 2\cdot g\cdot\left[(x_C-x_B)\cdot\cos\alpha + (y_C-y_B)\cdot\sin\alpha\right]\cdot\cos\varphi_5 +\\ 2\cdot g\cdot\left[(y_C-y_B)\cdot\cos\alpha - (x_C-x_B)\cdot\sin\alpha\right]\cdot\sin\varphi_5 +\\ 2\cdot g\cdot l_3\cdot\cos\alpha\cdot\cos(\varphi_5-\varphi_3) -\\ 2\cdot g\cdot l_3\cdot\sin\alpha\cdot\sin(\varphi_5-\varphi_3)\\ \\ l_4^2 = (x_C-x_D)^2 + (y_C-y_D)^2 + l_3^2 + e^2 +\\ 2\cdot l_3\cdot(x_C-x_D)\cdot\cos\varphi_3 + 2\cdot l_3\cdot(y_C-y_D)\cdot\sin\varphi_3\\ +2\cdot e\cdot(x_C-x_D)\cdot\cos\varphi_5 +\\ +2\cdot e\cdot(y_C-y_D)\cdot\sin\varphi_5 + 2\cdot e\cdot l_3\cdot\cos(\varphi_5-\varphi_3)\end{cases} \tag{6}$$

In order to solve the transcedental system (6), the method of successive approximations is used, considering the known trigonometric functions by knowing the angles φ_3 and φ_5 (they are given an initial value of any of these two angles for the priming of the iterative calculations) and the differences are calculated $\Delta\varphi_3$ and $\Delta\varphi_5$. The system (6) is rewritten into shape (8) by replacing the angles with the angle plus a difference according to the relations (7).

$$\left\{\begin{array}{l}
\cos\varphi_3 \Rightarrow \cos\varphi_3 - \Delta\varphi_3\cdot\sin\varphi_3\\
\sin\varphi_3 \Rightarrow \sin\varphi_3 + \Delta\varphi_3\cdot\cos\varphi_3\\
\\
\cos\varphi_5 \Rightarrow \cos\varphi_5 - \Delta\varphi_5\cdot\sin\varphi_5\\
\sin\varphi_5 \Rightarrow \sin\varphi_5 + \Delta\varphi_5\cdot\cos\varphi_5\\
\\
\cos(\varphi_5-\varphi_3) \Rightarrow\\
\cos(\varphi_5-\varphi_3) - (\Delta\varphi_5-\Delta\varphi_3)\cdot\sin(\varphi_5-\varphi_3)\\
\\
\sin(\varphi_5-\varphi_3) \Rightarrow\\
\sin(\varphi_5-\varphi_3) + (\Delta\varphi_5-\Delta\varphi_3)\cdot\cos(\varphi_5-\varphi_3)
\end{array}\right. \tag{7}$$

$$\left\{\begin{array}{l}
l_2^2 = (x_C-x_B)^2 + (y_C-y_B)^2 + l_3^2 + g^2 +\\
2\cdot l_3\cdot(x_C-x_B)\cdot\cos\varphi_3 + 2\cdot l_3\cdot(y_C-y_B)\cdot\sin\varphi_3\\
-2\cdot l_3\cdot(x_C-x_B)\cdot\sin\varphi_3\cdot\Delta\varphi_3 +\\
+2\cdot l_3\cdot(y_C-y_B)\cdot\cos\varphi_3\cdot\Delta\varphi_3 +\\
+2\cdot g\cdot\left[(x_C-x_B)\cdot\cos\alpha + (y_C-y_B)\cdot\sin\alpha\right]\cdot\cos\varphi_5\\
-2\cdot g\cdot\left[(x_C-x_B)\cdot\cos\alpha + (y_C-y_B)\cdot\sin\alpha\right]\cdot\sin\varphi_5\cdot\Delta\varphi_5\\
+2\cdot g\cdot\left[(y_C-y_B)\cdot\cos\alpha - (x_C-x_B)\cdot\sin\alpha\right]\cdot\sin\varphi_5\\
+2\cdot g\cdot\left[(y_C-y_B)\cdot\cos\alpha - (x_C-x_B)\cdot\sin\alpha\right]\cdot\cos\varphi_5\cdot\Delta\varphi_5\\
+2\cdot g\cdot l_3\cdot\cos\alpha\cdot\cos(\varphi_5-\varphi_3) -\\
-2\cdot g\cdot l_3\cdot\cos\alpha\cdot\sin(\varphi_5-\varphi_3)\cdot\Delta\varphi_5 +\\
+2\cdot g\cdot l_3\cdot\cos\alpha\cdot\sin(\varphi_5-\varphi_3)\cdot\Delta\varphi_3 -\\
-2\cdot g\cdot l_3\cdot\sin\alpha\cdot\sin(\varphi_5-\varphi_3) -\\
-2\cdot g\cdot l_3\cdot\sin\alpha\cdot\cos(\varphi_5-\varphi_3)\cdot\Delta\varphi_5 +\\
+2\cdot g\cdot l_3\cdot\sin\alpha\cdot\cos(\varphi_5-\varphi_3)\cdot\Delta\varphi_3\\
\\
l_4^2 = (x_C-x_D)^2 + (y_C-y_D)^2 + l_3^2 + e^2 +\\
2\cdot l_3\cdot(x_C-x_D)\cdot\cos\varphi_3 - 2\cdot l_3\cdot(x_C-x_D)\cdot\sin\varphi_3\cdot\Delta\varphi_3\\
+2\cdot l_3\cdot(y_C-y_D)\cdot\sin\varphi_3 + 2\cdot l_3\cdot(y_C-y_D)\cdot\cos\varphi_3\cdot\Delta\varphi_3\\
+2\cdot e\cdot(x_C-x_D)\cdot\cos\varphi_5 - 2\cdot e\cdot(x_C-x_D)\cdot\sin\varphi_5\cdot\Delta\varphi_5\\
+2\cdot e\cdot(y_C-y_D)\cdot\sin\varphi_5 + 2\cdot e\cdot(y_C-y_D)\cdot\cos\varphi_5\cdot\Delta\varphi_5\\
+2\cdot e\cdot l_3\cdot\cos(\varphi_5-\varphi_3) - 2\cdot e\cdot l_3\cdot\sin(\varphi_5-\varphi_3)\cdot\Delta\varphi_5\\
+2\cdot e\cdot l_3\cdot\sin(\varphi_5-\varphi_3)\cdot\Delta\varphi_3
\end{array}\right. \tag{8}$$

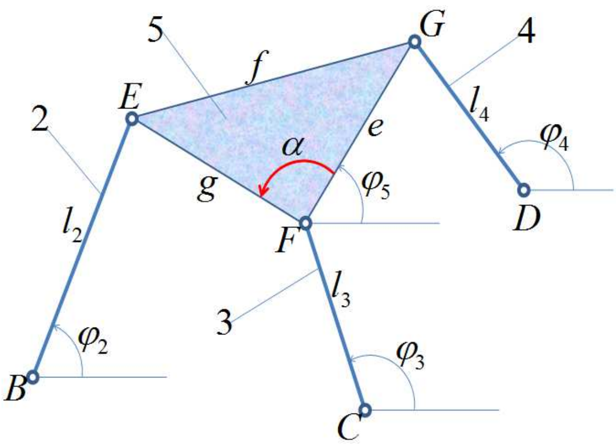

Fig. 1: The kinematic scheme of a 6R triad

The system (8) is arranged in the form (9) by grouping the corresponding terms so that a linear system of two equations with two unknowns appears, the unknown being $\Delta\varphi_3$ and $\Delta\ \varphi_5$.

It is now clear what the purpose of adding finite differences was. The nonlinear system has linearized in the form of a type system (10).

The solutions of the system (10) are given by the relations (11).

$$\left\{\begin{array}{l}
\{2\cdot l_3\cdot\left[(y_C-y_B)\cdot\cos\varphi_3 - (x_C-x_B)\cdot\sin\varphi_3\right]\\
+2\cdot g\cdot l_3\cdot\sin(\varphi_5-\varphi_3+\alpha)\}\cdot\Delta\varphi_3\\
2\cdot g\cdot\{(y_C-y_B)\cdot\cos\alpha\cdot\cos\varphi_5\\
-(x_C-x_B)\cdot\sin\alpha\cdot\cos\varphi_5 - (x_C-x_B)\cdot\cos\alpha\cdot\sin\varphi_5\\
-(y_C-y_B)\cdot\sin\alpha\cdot\sin\varphi_5 - l_3\cdot\left[\cos\alpha\cdot\sin(\varphi_5-\varphi_3)\right.\\
\left.+\sin\alpha\cdot\cos(\varphi_5-\varphi_3)\right]\}\cdot\Delta\varphi_5 =\\
= l_2^2 - (x_C-x_B)^2 - (y_C-y_B)^2 - l_3^2 - g^2\\
-2\cdot l_3\cdot(x_C-x_B)\cdot\cos\varphi_3 - 2\cdot l_3\cdot(y_C-y_B)\cdot\sin\varphi_3\\
-2\cdot g\cdot\{\left[(x_C-x_B)\cdot\cos\alpha + (y_C-y_B)\cdot\sin\alpha\right]\cdot\cos\varphi_5\\
+\left[(y_C-y_B)\cdot\cos\alpha - (x_C-x_B)\cdot\sin\alpha\right]\cdot\sin\varphi_5\} -\\
-2\cdot g\cdot l_3\cdot\left[\cos\alpha\cdot\cos(\varphi_5-\varphi_3) - \sin\alpha\cdot\sin(\varphi_5-\varphi_3)\right]\\
\\
2l_3\cdot\left[(y_C-y_D)\cos\varphi_3 - (x_C-x_D)\sin\varphi_3 + e\sin(\varphi_5-\varphi_3)\right]\Delta\varphi_3\\
+2e\cdot\left[(y_C-y_D)\cos\varphi_5 - (x_C-x_D)\sin\varphi_5 - l_3\sin(\varphi_5-\varphi_3)\right]\Delta\varphi_5\\
= l_4^2 - (x_C-x_D)^2 - (y_C-y_D)^2 - l_3^2 - e^2\\
-2\cdot l_3\cdot(x_C-x_D)\cdot\cos\varphi_3 - 2\cdot l_3\cdot(y_C-y_D)\cdot\sin\varphi_3\\
-2\cdot e\cdot(x_C-x_D)\cdot\cos\varphi_5 - 2\cdot e\cdot(y_C-y_D)\cdot\sin\varphi_5\\
-2\cdot e\cdot l_3\cdot\cos(\varphi_5-\varphi_3)
\end{array}\right. \tag{9}$$

$$\begin{cases} a_{11}\cdot\Delta\varphi_3 + a_{12}\cdot\Delta\varphi_5 = a_1 \\ a_{21}\cdot\Delta\varphi_3 + a_{22}\cdot\Delta\varphi_5 = a_2 \end{cases} \quad (10)$$

$$\begin{cases} \Delta = \begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} = a_{11}a_{22} - a_{12}a_{21}; \\ \Delta_3 = \begin{vmatrix} a_1 & a_{12} \\ a_2 & a_{22} \end{vmatrix} = a_1\cdot a_{22} - a_{12}\cdot a_2 \\ \Delta_5 = \begin{vmatrix} a_{11} & a_1 \\ a_{21} & a_2 \end{vmatrix} = a_{11}\cdot a_2 - a_1\cdot a_{21} \\ \Rightarrow \Delta\varphi_3 = \dfrac{\Delta_3}{\Delta};\ \Delta\varphi_5 = \dfrac{\Delta_5}{\Delta} \end{cases} \quad (11)$$

The coefficients of the system (10) are identified by (9) given by the relational system (12).

$$\begin{cases} a_{11} = 2\cdot l_3\cdot\left[\left(y_C - y_B\right)\cdot\cos\varphi_3 - \left(x_C - x_B\right)\cdot\sin\varphi_3 \right. \\ \left. +g\cdot\sin\left(\varphi_5 - \varphi_3 + \alpha\right)\right] \\ a_{12} = 2\cdot g\cdot\left[\left(y_C - y_B\right)\cdot\cos\left(\varphi_5+\alpha\right) - \right. \\ \left. \left(x_C - x_B\right)\sin\left(\varphi_5+\alpha\right) - l_3\cdot\sin\left(\varphi_5 - \varphi_3 + \alpha\right)\right] \\ a_1 = l_2^2 - l_3^2 - g^2 - \left(x_C - x_B\right)^2 - \left(y_C - y_B\right)^2 - \\ -2\cdot l_3\cdot\left[\left(x_C - x_B\right)\cdot\cos\varphi_3 + \left(y_C - y_B\right)\cdot\sin\varphi_3\right] - \\ -2\cdot g\cdot\left[\left(x_C - x_B\right)\cdot\cos\left(\varphi_5+\alpha\right) + \left(y_C - y_B\right)\cdot \right. \\ \left. \sin\left(\varphi_5+\alpha\right) + l_3\cdot\cos\left(\varphi_5 - \varphi_3 + \alpha\right)\right] \\ a_{21} = 2\cdot l_3\cdot \\ \left[\left(y_C - y_D\right)\cos\varphi_3 - \left(x_C - x_D\right)\sin\varphi_3 + e\sin\left(\varphi_5 - \varphi_3\right)\right] \\ a_{22} = 2\cdot e\cdot \\ \left[\left(y_C - y_D\right)\cos\varphi_5 - \left(x_C - x_D\right)\sin\varphi_5 - l_3\sin\left(\varphi_5 - \varphi_3\right)\right] \\ a_2 = l_4^2 - l_3^2 - e^2 - \left(x_C - x_D\right)^2 - \left(y_C - y_D\right)^2 - \\ -2\cdot l_3\cdot\left(x_C - x_D\right)\cdot\cos\varphi_3 - 2\cdot l_3\cdot\left(y_C - y_D\right)\cdot\sin\varphi_3 - \\ -2\cdot e\cdot\left(x_C - x_D\right)\cdot\cos\varphi_5 - 2\cdot e\cdot\left(y_C - y_D\right)\cdot\sin\varphi_5 - \\ -2\cdot e\cdot l_3\cdot\cos\left(\varphi_5 - \varphi_3\right) \end{cases} \quad (12)$$

In step 1 it is determinedΔφ $\Delta\phi_3^0\ and \Delta\phi_5^0$ in radii, which are added to the values initially considered to obtain the angular values for the first iteration, according to the system (13).

$$\begin{cases} \varphi_3^1 = \varphi_3^0 + \Delta\varphi_3^0 \\ \varphi_5^1 = \varphi_5^0 + \Delta\varphi_5^0 \end{cases} \quad (13)$$

If the values obtained are very close to the exact ones, the iterative process stops. Otherwise successive approximations will continue until the desired values are obtained. The final values φ_3 and φ_5 are considered to be OK when the error (difference) from their calculated value at the previous step is small enough.

It then returns to the initial positional systems to determine the other two values, φ_2 and φ_4 using the system (14):

$$\begin{cases} \begin{cases} \cos\varphi_2 = \dfrac{x_C - x_B + l_3\cdot\cos\varphi_3 + g\cdot\cos\left(\varphi_5+\alpha\right)}{l_2} \\ \sin\varphi_2 = \dfrac{y_C - y_B + l_3\cdot\sin\varphi_3 + g\cdot\sin\left(\varphi_5+\alpha\right)}{l_2} \end{cases} \\ \Rightarrow \varphi_2 \\ \varphi_2 = semn\left(\sin\varphi_2\right)\cdot\arccos\left(\cos\varphi_2\right) \\ \begin{cases} \cos\varphi_4 = \dfrac{x_C - x_D + l_3\cdot\cos\varphi_3 + e\cdot\cos\varphi_5}{l_4} \\ \sin\varphi_4 = \dfrac{y_C - y_D + l_3\cdot\sin\varphi_3 + e\cdot\sin\varphi_5}{l_4} \end{cases} \\ \Rightarrow \varphi_4 \\ \varphi_4 = semn\left(\sin\varphi_4\right)\cdot\arccos\left(\cos\varphi_4\right) \end{cases} \quad (14)$$

Once the four angular positions have been determined, the initial systems are derived to obtain angular velocities and then angular accelerations.

The positioning system (1) is first derived to obtain the linear speed system (15):

$$\begin{cases} \begin{cases} \dot{x}_B - l_2\cdot\sin\varphi_2\cdot\omega_2 = \\ \dot{x}_C - l_3\cdot\sin\varphi_3\cdot\omega_3 - g\cdot\sin\left(\varphi_5+\alpha\right)\cdot\omega_5 \\ \dot{y}_B + l_2\cdot\cos\varphi_2\cdot\omega_2 = \\ \dot{y}_C + l_3\cdot\cos\varphi_3\cdot\omega_3 + g\cdot\cos\left(\varphi_5+\alpha\right)\cdot\omega_5 \end{cases} \\ \begin{cases} \dot{x}_C - l_3\cdot\sin\varphi_3\cdot\omega_3 - e\cdot\sin\varphi_5\cdot\omega_5 = \\ \dot{x}_D - l_4\cdot\sin\varphi_4\cdot\omega_4 \\ \dot{y}_C + l_3\cdot\cos\varphi_3\cdot\omega_3 + e\cdot\cos\varphi_5\cdot\omega_5 = \\ \dot{y}_D + l_4\cdot\cos\varphi_4\cdot\omega_4 \end{cases} \end{cases} \quad (15)$$

For the simpler solution of the system (15) we eliminate in the first phase two of the four unknown by multiplying the first equation of the system with cosφ$_2$, the second with sinφ$_2$, the third with cosφ$_4$ and the last with sinφ$_4$. Then the first two equations and the last two are collected, resulting in the system (16) formed by two linear equations with two unknown equations:

$$\begin{cases}(\dot{x}_B-\dot{x}_C)\cdot\cos\varphi_2+(\dot{y}_B-\dot{y}_C)\cdot\sin\varphi_2= \\ =l_3\cdot\sin(\varphi_2-\varphi_3)\cdot\omega_3+g\cdot\sin(\varphi_2-\varphi_5-\alpha)\cdot\omega_5 \\ \\ (\dot{x}_D-\dot{x}_C)\cdot\cos\varphi_4+(\dot{y}_D-\dot{y}_C)\cdot\sin\varphi_4= \\ =l_3\cdot\sin(\varphi_4-\varphi_3)\cdot\omega_3+e\cdot\sin(\varphi_4-\varphi_5)\cdot\omega_5\end{cases} \tag{16}$$

To solve the system (16) we apply two steps.

In the first step, the first system equation is amplified with e.sin(φ$_4$-φ$_5$) and the second with $-g$. sin(φ$_2$-φ$_5$-α).

We then gather the two expressions obtained and result a relationship from which we explicitly explain it ω$_3$ (see expression 17):

$$\begin{cases}\omega_3=[e\cdot((\dot{x}_B-\dot{x}_C)\cdot\cos\varphi_2+(\dot{y}_B-\dot{y}_C)\cdot\sin\varphi_2)\cdot \\ \sin(\varphi_4-\varphi_5)-g\cdot((\dot{x}_D-\dot{x}_C)\cdot\cos\varphi_4+(\dot{y}_D-\dot{y}_C)\cdot \\ \sin\varphi_4)\cdot\sin(\varphi_2-\varphi_5-\alpha)]/[l_3\cdot \\ (e\sin(\varphi_2-\varphi_3)\sin(\varphi_4-\varphi_5)- \\ g\sin(\varphi_4-\varphi_3)\sin(\varphi_2-\varphi_5-\alpha))]\end{cases} \tag{17}$$

In the second step, the first system equation is amplified with sin(φ$_4$-φ$_3$) and the second with –sin(φ$_2$-φ$_3$).

We then gather the two expressions obtained and result a relationship from which we explicitly explain it ω$_5$ (see expression 18):

$$\begin{aligned}\omega_5=&\{[(\dot{x}_B-\dot{x}_C)\cdot\cos\varphi_2+(\dot{y}_B-\dot{y}_C)\cdot\sin\varphi_2]\cdot\sin(\varphi_4-\varphi_3)- \\ &-[(\dot{x}_D-\dot{x}_C)\cdot\cos\varphi_4+(\dot{y}_D-\dot{y}_C)\cdot\sin\varphi_4]\cdot\sin(\varphi_2-\varphi_3)\}/ \\ &[g\sin(\varphi_4-\varphi_3)\sin(\varphi_2-\varphi_5-\alpha)-e\sin(\varphi_2-\varphi_3)\sin(\varphi_4-\varphi_5)]\end{aligned} \tag{18}$$

From the system (15) it is then explained from the first two equations amplified with –sin φ$_2$ respectively cos φ$_2$ the angular velocity ω$_2$, (relation 19), and from the last two relations amplified with –sin φ$_4$ respectively cos φ$_4$ the angular velocity, ω$_4$ (relation 20):

$$\begin{aligned}\omega_2=&\frac{(\dot{x}_B-\dot{x}_C)\cdot\sin\varphi_2+(\dot{y}_C-\dot{y}_B)\cdot\cos\varphi_2}{l_2}+ \\ &+\frac{l_3\cdot\omega_3\cdot\cos(\varphi_3-\varphi_2)+g\cdot\omega_5\cdot\cos(\varphi_2-\varphi_5-\alpha)}{l_2}\end{aligned} \tag{19}$$

$$\begin{aligned}\omega_4=&\frac{(\dot{x}_D-\dot{x}_C)\cdot\sin\varphi_4+(\dot{y}_C-\dot{y}_D)\cdot\cos\varphi_4}{l_4}+ \\ &+\frac{l_3\cdot\omega_3\cdot\cos(\varphi_4-\varphi_3)+e\cdot\omega_5\cdot\cos(\varphi_4-\varphi_5)}{l_4}\end{aligned} \tag{20}$$

Appropriate angular accelerations are obtained most safely by direct derivation of corresponding angular velocities expressions.

Write the expression (17) deployed (in form 21) to make it easier to derive.

$$\begin{cases}\omega_3 l_3[e\sin(\varphi_2-\varphi_3)\sin(\varphi_4-\varphi_5)- \\ g\sin(\varphi_4-\varphi_3)\sin(\varphi_2-\varphi_5-\alpha)] \\ =e\cdot[(\dot{x}_B-\dot{x}_C)\cdot\cos\varphi_2+(\dot{y}_B-\dot{y}_C)\cdot\sin\varphi_2]\cdot \\ \sin(\varphi_4-\varphi_5)- \\ -g\cdot[(\dot{x}_D-\dot{x}_C)\cdot\cos\varphi_4+(\dot{y}_D-\dot{y}_C)\cdot\sin\varphi_4]\cdot \\ \sin(\varphi_2-\varphi_5-\alpha)\end{cases} \tag{21}$$

The expression (21) of the angular velocity ω$_3$ in relation to time is directly derived, and the corresponding angular acceleration (22) expression is obtained ε$_3$, which then immediately becomes the form (23):

$$\begin{cases}\varepsilon_3 l_3[e\sin(\varphi_2-\varphi_3)\sin(\varphi_4-\varphi_5)- \\ g\sin(\varphi_4-\varphi_3)\sin(\varphi_2-\varphi_5-\alpha)] \\ =-\omega_3\cdot[l_3\cdot e\cdot\cos(\varphi_2-\varphi_3)\cdot\sin(\varphi_4-\varphi_5) \\ \cdot(\omega_2-\omega_3)+l_3\cdot e\cdot\sin(\varphi_2-\varphi_3)\cdot\cos(\varphi_4-\varphi_5)\cdot \\ (\omega_4-\omega_5)- \\ -l_3\cdot g\cdot\cos(\varphi_4-\varphi_3)\cdot\sin(\varphi_2-\varphi_5-\alpha)\cdot(\omega_4-\omega_3)- \\ -l_3\cdot g\cdot\sin(\varphi_4-\varphi_3)\cdot\cos(\varphi_2-\varphi_5-\alpha)\cdot(\omega_2-\omega_5)]+ \\ +e\cdot[(\ddot{x}_B-\ddot{x}_C)\cdot\cos\varphi_2+(\ddot{y}_B-\ddot{y}_C)\cdot\sin\varphi_2- \\ -(\dot{x}_B-\dot{x}_C)\cdot\sin\varphi_2\cdot\omega_2+(\dot{y}_B-\dot{y}_C)\cdot\cos\varphi_2\cdot\omega_2]\cdot \\ \sin(\varphi_4-\varphi_5)+e[(\dot{x}_B-\dot{x}_C)\cos\varphi_2+(\dot{y}_B-\dot{y}_C)\sin\varphi_2] \\ \cdot\cos(\phi_4-\phi_5)(\omega_4-\omega_5)- \\ -g\cdot[(\ddot{x}_D-\ddot{x}_C)\cdot\cos\varphi_4+(\ddot{y}_D-\ddot{y}_C)\cdot\sin\varphi_4- \\ -(\dot{x}_D-\dot{x}_C)\sin\varphi_4\cdot\omega_4+(\dot{y}_D-\dot{y}_C)\cos\varphi_4\cdot\omega_4] \\ \cdot\sin(\varphi_2-\varphi_5-\alpha)- \\ g[(\dot{x}_D-\dot{x}_C)\cos\varphi_4+(\dot{y}_D-\dot{y}_C)\sin\varphi_4] \\ \cdot\cos(\varphi_2-\varphi_5-\alpha)(\omega_2-\omega_5)\end{cases} \tag{22}$$

$$\begin{cases}\varepsilon_3=\{-\omega_3\cdot[l_3\cdot e\cdot\cos(\varphi_2-\varphi_3)\cdot\sin(\varphi_4-\varphi_5)\cdot(\omega_2-\omega_3)+\\ +l_3\cdot e\cdot\sin(\varphi_2-\varphi_3)\cdot\cos(\varphi_4-\varphi_5)\cdot(\omega_4-\omega_5)-\\ -l_3\cdot g\cdot\cos(\varphi_4-\varphi_3)\cdot\sin(\varphi_2-\varphi_5-\alpha)\cdot(\omega_4-\omega_3)-\\ -l_3\cdot g\cdot\sin(\varphi_4-\varphi_3)\cdot\cos(\varphi-\varphi_5-\alpha)\cdot(\omega_2-\omega_5)]+\\ +e\cdot[(\ddot{x}_B-\ddot{x}_C)\cdot\cos\varphi_2+(\ddot{y}_B-\ddot{y}_C)\cdot\sin\varphi_2-\\ -(\dot{x}_B-\dot{x}_C)\cdot\sin\varphi_2\cdot\omega_2+(\dot{y}_B-\dot{y}_C)\cdot\cos\varphi_2\cdot\omega_2]\cdot\sin(\varphi_4-\varphi_5)+\\ +e[(\dot{x}_B-\dot{x}_C)\cos\varphi_2+(\dot{y}_B-\dot{y}_C)\sin\varphi_2]\cos(\varphi_4-\varphi_5)(\omega_4-\omega_5)-\\ -g\cdot[(\ddot{x}_D-\ddot{x}_C)\cdot\cos\varphi_4+(\ddot{y}_D-\ddot{y}_C)\cdot\sin\varphi_4-\\ -(\dot{x}_D-\dot{x}_C)\sin\varphi_4\cdot\omega_4+(\dot{y}_D-\dot{y}_C)\cos\varphi_4\cdot\omega_4]\sin(\varphi_2-\varphi_5-\alpha)-\\ g[(\dot{x}_D-\dot{x}_C)\cos\varphi_4+(\dot{y}_D-\dot{y}_C)\sin\varphi_4]\cos(\varphi_2-\varphi_5-\alpha)(\omega_2-\omega_5)\}\\ :[l_3 e\sin(\varphi_2-\varphi_3)\sin(\varphi_4-\varphi_5)-l_3 g\sin(\varphi_4-\varphi_3)\sin(\varphi_2-\varphi_5-\alpha)]\end{cases}\tag{23}$$

The angular velocity ω_5 (relationship 24) is then written so that it can easily be derived:

$$\begin{cases}\omega_5[g\sin(\varphi_4-\varphi_3)\sin(\varphi_2-\varphi_5-\alpha)-e\sin(\varphi_2-\varphi_3)\sin(\varphi_4-\phi_5)]\\ =[(\dot{x}_B-\dot{x}_C)\cdot\cos\varphi_2+(\dot{y}_B-\dot{y}_C)\cdot\sin\varphi_2]\cdot\sin(\varphi_4-\varphi_3)\\ -[(\dot{x}_D-\dot{x}_C)\cdot\cos\varphi_4+(\dot{y}_D-\dot{y}_C)\cdot\sin\varphi_4]\cdot\sin(\varphi_2-\varphi_3)\end{cases}\tag{24}$$

The expression (24) is derived in relation to time to obtain the expression of the angular acceleration ε_5 directly. Thus, the relation (25) is obtained, from which the value of the angular acceleration ε_5 in the form (26) is then explained:

$$\begin{cases}\varepsilon_5[g\sin(\varphi_4-\varphi_3)\sin(\varphi_2-\varphi_5-\alpha)-e\sin(\varphi_2-\varphi_3)\sin(\varphi_4-\varphi_5)]\\ =-\omega_5\cdot[g\cdot\cos(\varphi_2-\varphi_5-\alpha)\cdot\sin(\varphi_4-\varphi_3)\cdot(\omega_2-\omega_5)+g\cdot\sin(\varphi_2-\varphi_5-\alpha)\cdot\cos(\varphi_4-\varphi_3)\cdot(\omega_4-\omega_3)\\ -e\cdot\cos(\varphi_4-\varphi_5)\cdot\sin(\varphi_2-\varphi_3)\cdot(\omega_4-\omega_5)-e\cdot\sin(\varphi_4-\varphi_5)\cdot\cos(\varphi_2-\varphi_3)\cdot(\omega_2-\omega_3)]\\ +\sin(\varphi_4-\varphi_3)\cdot[(\ddot{x}_B-\ddot{x}_C)\cdot\cos\varphi_2+(\ddot{y}_B-\ddot{y}_C)\cdot\sin\varphi_2\\ -(\dot{x}_B-\dot{x}_C)\cdot\sin\varphi_2\cdot\omega_2+(\dot{y}_B-\dot{y}_C)\cdot\cos\varphi_2\cdot\omega_2]\\ +[(\dot{x}_B-\dot{x}_C)\cos\varphi_2+(\dot{y}_B-\dot{y}_C)\sin\varphi_2]\cdot\cos(\varphi_4-\varphi_3)\cdot(\omega_4-\omega_3)\\ -[(\ddot{x}_D-\ddot{x}_C)\cdot\cos\varphi_4+(\ddot{y}_D-\ddot{y}_C)\cdot\sin\varphi_4-(\dot{x}_D-\dot{x}_C)\cdot\sin\varphi_4\cdot\omega_4\\ +(\dot{y}_D-\dot{y}_C)\cdot\cos\varphi_4\cdot\omega_4]\cdot\sin(\varphi_2-\varphi_3)-[(\dot{x}_D-\dot{x}_C)\cdot\cos\varphi_4+(\dot{y}_D-\dot{y}_C)\cdot\sin\varphi_4]\cdot\cos(\varphi_2-\varphi_3)\cdot(\omega_2-\omega_3)\end{cases}\tag{25}$$

$$\begin{cases}\varepsilon_5=\{-\omega_5\cdot[g\cdot\cos(\varphi_2-\varphi_5-\alpha)\cdot\sin(\varphi_4-\varphi_3)\cdot(\omega_2-\omega_5)\\ +g\cdot\sin(\varphi_2-\varphi_5-\alpha)\cdot\cos(\varphi_4-\varphi_3)\cdot(\omega_4-\omega_3)-e\cdot\cos(\varphi_4-\varphi_5)\cdot\sin(\varphi_2-\varphi_3)\cdot(\omega_4-\omega_5)\\ -e\cdot\sin(\varphi_4-\varphi_5)\cdot\cos(\varphi_2-\varphi_3)\cdot(\omega_2-\omega_3)]+\sin(\varphi_4-\varphi_3)\cdot[(\ddot{x}_B-\ddot{x}_C)\cdot\cos\varphi_2+(\ddot{y}_B-\ddot{y}_C)\cdot\sin\varphi_2\\ -(\dot{x}_B-\dot{x}_C)\cdot\sin\varphi_2\cdot\omega_2+(\dot{y}_B-\dot{y}_C)\cdot\cos\varphi_2\cdot\omega_2]\\ +[(\dot{x}_B-\dot{x}_C)\cos\varphi_2+(\dot{y}_B-\dot{y}_C)\sin\varphi_2]\cdot\cos(\varphi_4-\varphi_3)\cdot(\omega_4-\omega_3)\\ [(\ddot{x}_D-\ddot{x}_C)\cdot\cos\varphi_4+(\ddot{y}_D-\ddot{y}_C)\cdot\sin\varphi_4-(\dot{x}_D-\dot{x}_C)\cdot\sin\varphi_4\cdot\omega_4+(\dot{y}_D-\dot{y}_C)\cdot\cos\varphi_4\cdot\omega_4]\cdot\sin(\varphi_2-\varphi_3)\\ -[(\dot{x}_D-\dot{x}_C)\cos\varphi_4+(\dot{y}_D-\dot{y}_C)\sin\varphi_4]\cos(\varphi_2-\varphi_3)(\omega_2-\omega_3)\}\\ :[g\sin(\varphi_4-\varphi_3)\sin(\varphi_2-\varphi_5-\alpha)-e\sin(\varphi_2-\varphi_3)\sin(\varphi_4-\varphi_5)]\end{cases}\tag{26}$$

The expression (27) of the angular velocity ω_2 is further derived and the angular acceleration ε_2 (relationship 28) is obtained directly:

$$\omega_2=\frac{(\dot{x}_B-\dot{x}_C)\cdot\sin\varphi_2+(\dot{y}_C-\dot{y}_B)\cdot\cos\varphi_2}{l_2}+\frac{l_3\cdot\omega_3\cdot\cos(\varphi_3-\varphi_2)+g\cdot\omega_5\cdot\cos(\varphi_2-\varphi_5-\alpha)}{l_2}\tag{27}$$

$$\begin{cases}\varepsilon_2=\frac{1}{l_2}\cdot[(\ddot{x}_B-\ddot{x}_C)\cdot\sin\varphi_2+(\ddot{y}_C-\ddot{y}_B)\cdot\cos\varphi_2\\ +(\dot{x}_B-\dot{x}_C)\cdot\cos\varphi_2\cdot\omega_2-(\dot{y}_C-\dot{y}_B)\cdot\sin\varphi_2\cdot\omega_2\\ +l_3\cdot\varepsilon_3\cdot\cos(\varphi_3-\varphi_2)-l_3\cdot\omega_3\cdot\sin(\varphi_3-\varphi_2)\cdot(\omega_3-\omega_2)\\ +g\cdot\varepsilon_5\cdot\cos(\varphi_2-\varphi_5-\alpha)-g\cdot\omega_5\cdot\sin(\varphi_2-\varphi_5-\alpha)\cdot(\omega_2-\omega_5)]\end{cases}\tag{28}$$

Then the expression (29) of the angular velocity ω_4 is derived, and the expression of the angular acceleration ε_4 (relationship 30) is obtained:

$$\omega_4 = \frac{(\dot{x}_D - \dot{x}_C)\cdot\sin\varphi_4 + (\dot{y}_C - \dot{y}_D)\cdot\cos\varphi_4}{l_4} + \frac{l_3\cdot\omega_3\cdot\cos(\varphi_4-\varphi_3) + e\cdot\omega_5\cdot\cos(\varphi_4-\varphi_5)}{l_4} \tag{29}$$

$$\begin{cases} \varepsilon_4 = \dfrac{1}{l_4}\cdot\left[(\ddot{x}_D - \ddot{x}_C)\cdot\sin\varphi_4 + (\ddot{y}_C - \ddot{y}_D)\cdot\cos\varphi_4\right. \\ +(\dot{x}_D-\dot{x}_C)\cdot\cos\varphi_4\cdot\omega_4 - (\dot{y}_C-\dot{y}_D)\cdot\sin\varphi_4\cdot\omega_4 \\ +l_3\cdot\varepsilon_3\cdot\cos(\varphi_4-\varphi_3) - l_3\cdot\omega_3\cdot\sin(\varphi_4-\varphi_3)\cdot(\omega_4-\omega_3) \\ \left.+e\cdot\varepsilon_5\cdot\cos(\varphi_4-\varphi_5) - e\cdot\omega_5\cdot\sin(\varphi_4-\varphi_5)\cdot(\omega_4-\omega_5)\right] \end{cases} \tag{30}$$

Results and Discussion

The kinematics of inner dome couplings and weight centers on each element of the 6R diaphragm (Fig. 2 and relational systems 31-32) can be further determined:

$$\begin{cases} \begin{cases} x_E = x_B + l_2\cdot\cos\varphi_2 \\ y_E = y_B + l_2\cdot\sin\varphi_2 \end{cases} \Rightarrow \begin{cases} \dot{x}_E = \dot{x}_B - l_2\cdot\sin\varphi_2\cdot\omega_2 \\ \dot{y}_E = \dot{y}_B + l_2\cdot\cos\varphi_2\cdot\omega_2 \end{cases} \Rightarrow \begin{cases} \ddot{x}_E = \ddot{x}_B - l_2\cdot\cos\varphi_2\cdot\omega_2^2 - l_2\cdot\sin\varphi_2\cdot\varepsilon_2 \\ \ddot{y}_E = \ddot{y}_B - l_2\cdot\sin\varphi_2\cdot\omega_2^2 + l_2\cdot\cos\varphi_2\cdot\varepsilon_2 \end{cases} \\ \begin{cases} x_F = x_C + l_3\cdot\cos\varphi_3 \\ y_F = y_C + l_3\cdot\sin\varphi_3 \end{cases} \Rightarrow \begin{cases} \dot{x}_F = \dot{x}_C - l_3\cdot\sin\varphi_3\cdot\omega_3 \\ \dot{y}_F = \dot{y}_C + l_3\cdot\cos\varphi_3\cdot\omega_3 \end{cases} \Rightarrow \begin{cases} \ddot{x}_F = \ddot{x}_C - l_3\cdot\cos\varphi_3\cdot\omega_3^2 - l_3\cdot\sin\varphi_3\cdot\varepsilon_3 \\ \ddot{y}_F = \ddot{y}_C - l_3\cdot\sin\varphi_3\cdot\omega_3^2 + l_3\cdot\cos\varphi_3\cdot\varepsilon_3 \end{cases} \\ \begin{cases} x_G = x_D + l_4\cdot\cos\varphi_4 \\ y_G = y_D + l_4\cdot\sin\varphi_4 \end{cases} \Rightarrow \begin{cases} \dot{x}_G = \dot{x}_D - l_4\cdot\sin\varphi_4\cdot\omega_4 \\ \dot{y}_G = \dot{y}_D + l_4\cdot\cos\varphi_4\cdot\omega_4 \end{cases} \Rightarrow \begin{cases} \ddot{x}_G = \ddot{x}_D - l_4\cdot\cos\varphi_4\cdot\omega_4^2 - l_4\cdot\sin\varphi_4\cdot\varepsilon_4 \\ \ddot{y}_G = \ddot{y}_D - l_4\cdot\sin\varphi_4\cdot\omega_4^2 + l_4\cdot\cos\varphi_4\cdot\varepsilon_4 \end{cases} \end{cases} \tag{31}$$

$$\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} \Rightarrow \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} \Rightarrow \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_C + s_3\cdot\cos\varphi_3 \\ y_{G_3} = y_C + s_3\cdot\sin\varphi_3 \end{cases} \Rightarrow \begin{cases} \dot{x}_{G_3} = \dot{x}_C - s_3\cdot\sin\varphi_3\cdot\omega_3 \\ \dot{y}_{G_3} = \dot{y}_C + s_3\cdot\cos\varphi_3\cdot\omega_3 \end{cases} \Rightarrow \begin{cases} \ddot{x}_{G_3} = \ddot{x}_C - 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}_C - s_3\cdot\sin\varphi_3\cdot\omega_3^2 + s_3\cdot\cos\varphi_3\cdot\varepsilon_3 \end{cases} \\ \begin{cases} x_{G_4} = x_D + s_4\cdot\cos\varphi_4 \\ y_{G_4} = y_D + s_4\cdot\sin\varphi_4 \end{cases} \Rightarrow \begin{cases} \dot{x}_{G_4} = \dot{x}_D - s_4\cdot\sin\varphi_4\cdot\omega_4 \\ \dot{y}_{G_4} = \dot{y}_D + s_4\cdot\cos\varphi_4\cdot\omega_4 \end{cases} \Rightarrow \begin{cases} \ddot{x}_{G_4} = \ddot{x}_D - s_4\cdot\cos\varphi_4\cdot\omega_4^2 - s_4\cdot\sin\varphi_4\cdot\varepsilon_4 \\ \ddot{y}_{G_4} = \ddot{y}_D - s_4\cdot\sin\varphi_4\cdot\omega_4^2 + s_4\cdot\cos\varphi_4\cdot\varepsilon_4 \end{cases} \\ \begin{cases} x_{G_5} = x_F + s_5\cdot\cos(\varphi_5+\beta) \\ y_{G_5} = y_F + s_5\cdot\sin(\varphi_5+\beta) \end{cases} \Rightarrow \begin{cases} \dot{x}_{G_5} = \dot{x}_F - s_5\cdot\sin(\varphi_5+\beta)\cdot\omega_5 \\ \dot{y}_{G_5} = \dot{y}_F + s_5\cdot\cos(\varphi_5+\beta)\cdot\omega_5 \end{cases} \\ \Rightarrow \begin{cases} \ddot{x}_{G_5} = \ddot{x}_F - s_5\cdot\cos(\varphi_5+\beta)\cdot\omega_5^2 - s_5\cdot\sin(\varphi_5+\beta)\cdot\varepsilon_5 \\ \ddot{y}_{G_5} = \ddot{y}_F - s_5\cdot\sin(\varphi_5+\beta)\cdot\omega_5^2 + s_5\cdot\cos(\varphi_5+\beta)\cdot\varepsilon_5 \end{cases} \end{cases} \tag{32}$$

With the help of the kinematics of the center of gravity, in the future, it is possible to determine the triad kinetostatic and its dynamics.

Such groups have applications in mechanics, mechanisms, robots, thermal engines, aircraft.

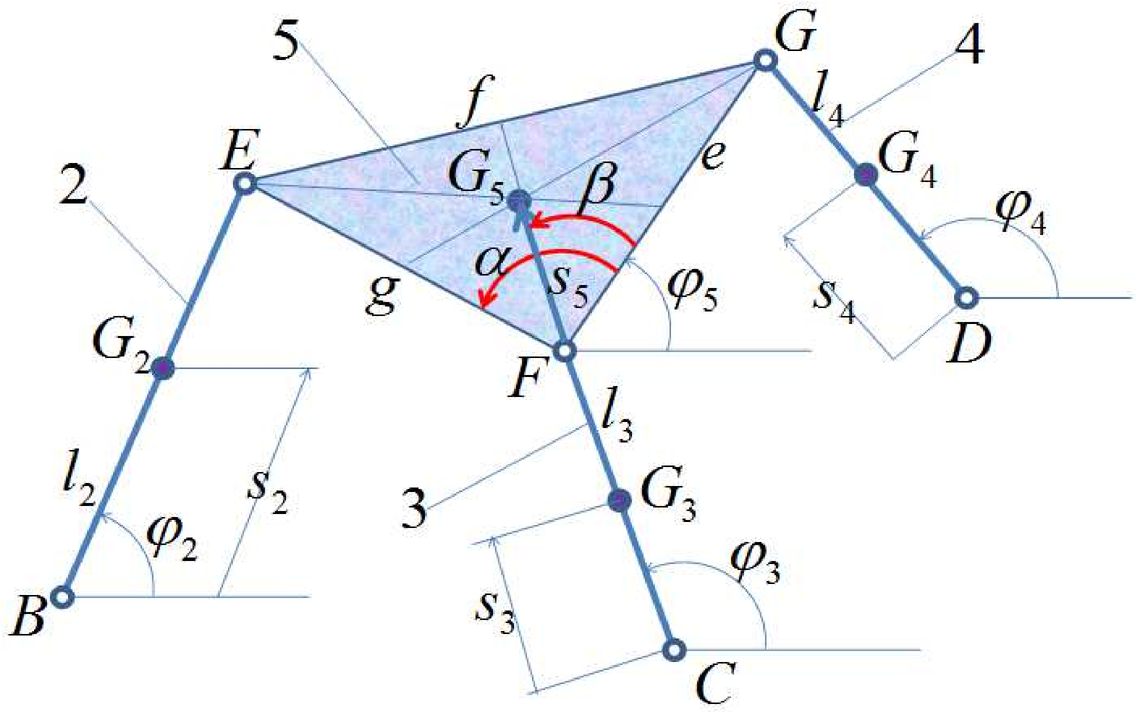

Fig. 2: The kinematics of gravity centers at a 6R triad

Conclusion

The present work is intended presenting a triad kinematics general used only with the kinematic couplings rotational (C5), because such approaches are rare in the area, although triad is a structured group Assuric often used. The calculation theoretical method presented is an analytical one.

Such groups have applications in mechanics, mechanisms, robots, thermal engines, aircraft.

Acknowledgement

This text was acknowledged and appreciated by Dr. Veturia CHIROIU Honorific member of Technical Sciences Academy of Romania (ASTR) PhD supervisor in Mechanical Engineering.

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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