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An Analytical Method for Determining Forces within a Triad

[1]Florian Ion Tiberiu Petrescu, [2]Taher M. Abu-Lebdeh and [3]Antonio Apicella

[1]*ARoTMM-IFToMM, Bucharest Polytechnic University, Bucharest, (CE), Romania*
[2]*North Carolina A and T State Univesity, United States*
[3]*Department of Architecture and Industrial Design, Advanced Material Lab, Second University of Naples, 81031 Aversa (CE), Italy*

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Corresponding Author:
Florian Ion Tiberiu Petrescu
ARoTMM-IFToMM, Bucharest Polytechnic University,
Bucharest, (CE), Romania
Email: scipub02@gmail.com

Abstract: The paper presents an original analytical method used in determining the forces within a triad structural group. If the triad is in the mechanical equivalent of the transistor in electronics, representing a very useful structural group, while the transistor is no longer a puzzlement from a long time period, the triad was not too studied analytically, generally being approached by graphic design methods, very elaborated, sometimes very difficult. For this reason, this paper tries to fill a gap in this field. A concrete example of calculation is also presented.

Keywords: Robots, Manipulators, Automation, Engines, Mechanical Transmissions, Kinematics, Forces, Dynamics, Dynamic Kinematics, Dynamic Forces

Introduction

A triad is a widely used asurical group, consisting of four elements and six kinematic couplings (Fig. 1).

The analytic cinematic of a triad was already presented in a previous paper (Petrescu *et al*., 2018).

In presented paper one can show an original analytical method used in determining the forces within a triad structural group (Frăţilă *et al*., 2011; Pelecudi, 1967; Antonescu, 2000; Comănescu *et al*., 2010; Aversa *et al*., 2016a; 2016b; 2016c; 2016d; 2017a; 2017b; 2017c; 2017d; 2017e; 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; 2016b; 2016c; 2016d; 2016e; 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; Petrescu and Calautit, 2016a; 2016b; 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; List the First Flights, From Wikipedia; Chen and Patton, 1999; Fernandez *et al*., 2005; Fonod *et al*., 2015; Lu *et al*., 2015; 2016; Murray *et al*., 2010; Palumbo *et al*., 2012; Patre and Joshi, 2011; Sevil and Dogan, 2015; Sun and Joshi, 2009; Crickmore, 1997; Goodall, 2003; Graham, 2002; Jenkins, 2001; Landis and Dennis, 2005; Clément, Wikipedia; Cayley, Wikipedia; Coandă-1910, Wikipedia; Gunston, 2010; Laming, 2000; Norris, 2010; Goddard, 1916; Kaufman, 1959; Oberth, 1955; Cataldo, 2006; Gruener, 2006; Sherson *et al*., 2006; Williams, 1995; Venkataraman, 1992; Oppenheimer and Volkoff, 1939; Michell, 1784; Droste, 1915; Finkelstein, 1958; Gorder, 2015; Hewish, 1970).

Figure 2 shows the forces at a triad 6R.

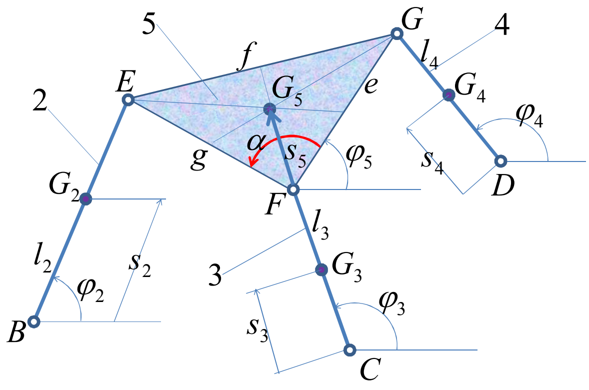

Fig. 1: A triad is a widely used asurical group, consisting of four elements and six kinematic couplings

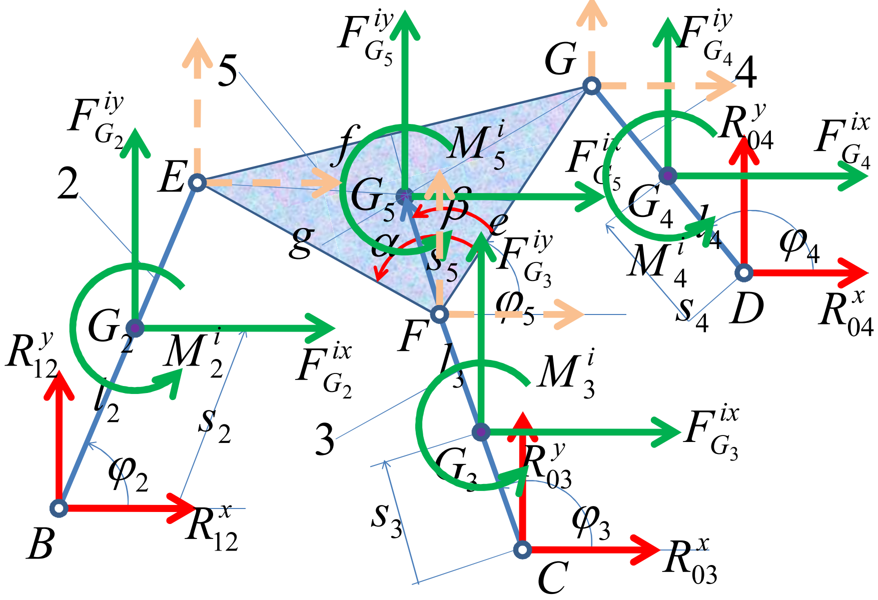

Fig. 2: The forces at a triad 6R

Materials and Methods

The inertial forces torsor (Fig. 2) is expressed with relations (I):

$$\begin{cases} F_{G_2}^{ix} = -m_2 \cdot \ddot{x}_{G_2} \\ F_{G_2}^{iy} = -m_2 \cdot \ddot{y}_{G_2} \\ M_2^i = -J_{G_2} \cdot \varepsilon_2 \end{cases} \quad \begin{cases} F_{G_3}^{ix} = -m_3 \cdot \ddot{x}_{G_3} \\ F_{G_3}^{iy} = -m_3 \cdot \ddot{y}_{G_3} \\ M_3^i = -J_{G_3} \cdot \varepsilon_3 \end{cases}$$
$$\begin{cases} F_{G_4}^{ix} = -m_4 \cdot \ddot{x}_{G_4} \\ F_{G_4}^{iy} = -m_4 \cdot \ddot{y}_{G_4} \\ M_4^i = -J_{G_4} \cdot \varepsilon_4 \end{cases} \quad \begin{cases} F_{G_5}^{ix} = -m_5 \cdot \ddot{x}_{G_5} \\ F_{G_5}^{iy} = -m_5 \cdot \ddot{y}_{G_5} \\ M_5^i = -J_{G_5} \cdot \varepsilon_5 \end{cases} \quad \text{(I)}$$

For a partial decoupling of the coupling reactions, a sum of moments from element 2 to point *E*, a sum of moments from element 3 from point *F*, is written first, a sum of moments from the entire triad to point *D* and a sum of moments relative to the *G* point on the elements (2, 3, 5).

This creates a linear system of four degree equations with four unknowns R_{12}^x, R_{12}^y, R_{03}^x, R_{03}^y. It is solved by determinants and then two sums of forces are written over the entire triad projected on the axes *x* and *y* respectively, from which the last two reactions from the input couplers are obtained, R_{04}^x and R_{04}^y.

There are sums of forces projected on the *x* and *y* axes, on element 2, then on element 3 and finally on element 4. They also donate the reaction pairs from the inner couplers of triad 6*R*.

Results and Discussion

As an example of calculation one will present a main mechanism of an original engine (Fig. 3).

When the mechanism is driven by the piston, by eliminating the leading element, a triad-type structural group is obtained.

We can write these forces and speeds (relations of the system 1). The first change of presented model, having seeable the classical model (the engine mechanism of an Otto motor), is that we can use two connecting-rod, (elements 2 and 3) and also the use of the B couple, a twin couple: Of rotation and translation. Proposed new motor mechanism could be a new mechanism and his practicality is completely different from the classical mechanism's known. The nice advantage of this new mechanism is that it is regulated to own a high zone of constant acceleration of the mechanism piston (the part range five). The potency of this mechanism is that the same just like the Otto mechanism. The structural cluster 2-4 (a dyad) will improve the motor practicality while not harm of power. The mechanics relations with kinematic functions are the subsequent (1-11):

$$a^2 = l_0^2 + l_1^2 - 2 \cdot l_0 \cdot l_1 \cdot \sin\varphi_1 \quad (1)$$

$$\cos\varphi_2 = -\frac{l_1 \cdot \cos\varphi_1}{a} \quad (2)$$

$$\cos\varphi_3 = \frac{e - l_1 \cdot \cos\varphi_1 - l_2 \cdot \cos\varphi_2}{l_3} \quad (3)$$

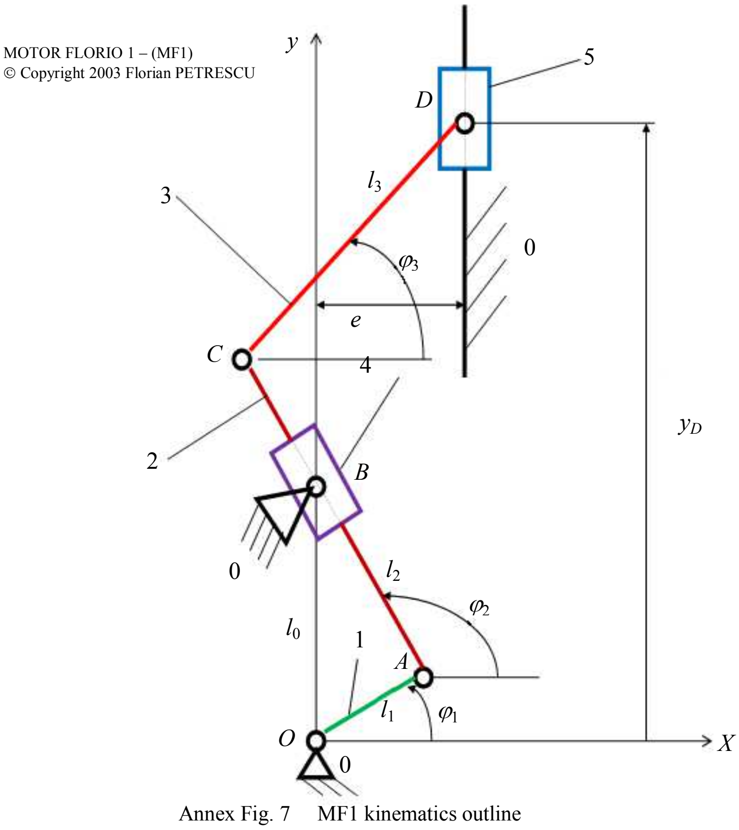

Fig. 3: MF1 kinematics outline

$$y_D = l_1 \cdot \sin\varphi_1 + l_2 \cdot \sin\varphi_2 + l_3 \cdot \sin\varphi_3 \tag{4}$$

$$\omega_2 = -\frac{l_1 \cdot \cos(\varphi_1 - \varphi_2)}{a} \cdot \omega_1 \tag{5}$$

$$\dot{a} = -\frac{l_0 \cdot l_1 \cdot \omega_1 \cdot \cos\varphi_1}{a} \tag{6}$$

$$\left\{\omega_3 = \frac{l_1 \cdot \omega_1}{a \cdot l_3} \cdot \begin{bmatrix} l_0 \cdot \cos\varphi_1 \cdot \sin(\varphi_3 - \varphi_2) + \\ b \cdot \cos(\varphi_1 - \varphi_2) \cdot \cos(\varphi_3 - \varphi_2) \end{bmatrix}\right. \tag{7}$$

$$\{\dot{y}_D = \omega_1 \cdot l_1 \cdot \cos\varphi_1 + \omega_2 \cdot l_2 \cdot \cos\varphi_2 + \omega_3 \cdot l_3 \cdot \cos\varphi_3 \tag{8}$$

$$\varepsilon_2 = \frac{l_1 \cdot \omega_1 \cdot (\omega_1 - \omega_2) \cdot \sin(\varphi_1 - \varphi_2) - \omega_2 \cdot \dot{a}}{a} \tag{9}$$

$$\left\{\varepsilon_3 = \frac{l_1 \cdot \omega_1}{a \cdot l_3} \cdot \begin{bmatrix} -l_0 \cdot \omega_1 \cdot \sin\varphi_1 \cdot \sin(\varphi_3 - \varphi_2) \\ +l_0 \cdot (\omega_3 - \omega_2) \cdot \cos\varphi_1 \cdot \cos(\varphi_3 - \varphi_2) \\ -b \cdot (\omega_1 - \omega_2) \cdot \sin(\varphi_1 - \varphi_2) \\ \cdot \cos(\varphi_3 - \varphi_2) - b \cdot (\omega_3 - \omega_2) \\ \cdot \cos(\varphi_1 - \varphi_2) \cdot \sin(\varphi_3 - \varphi_2) \end{bmatrix} - \frac{\dot{a}}{a} \cdot \omega_3\right. \tag{10}$$

$$\begin{cases} \ddot{y}_D = -\omega_1^2 \cdot l_1 \cdot \sin\varphi_1 - \omega_2^2 \cdot l_2 \cdot \sin\varphi_2 + \\ \varepsilon_2 \cdot l_2 \cdot \cos\varphi_2 - \omega_3^2 \cdot l_3 \cdot \sin\varphi_3 + \varepsilon_3 \cdot l_3 \cdot \cos\varphi_3 \end{cases} \tag{11}$$

One can determine the momentary mechanical efficiency, when the mechanism works like a steam roller, if it determines the forces distribution from the crank to the piston (Fig. 4); relations 12-19:

$$\begin{cases} F_n = F_m \cdot \sin(\varphi_2 - \varphi_1) \\ F_{\tau_A} = F_m \cdot \cos(\varphi_2 - \varphi_1) \end{cases} \tag{12}$$

$$F_{\tau_C} = \frac{a}{b} \cdot F_{\tau_A} = \frac{a}{b} \cdot F_m \cdot \cos(\varphi_2 - \varphi_1) \tag{13}$$

$$\begin{cases} F_n^I = F_n \cdot \cos(\varphi_2 - \varphi_3) \\ F_{\tau_C}^I = F_{\tau_C} \cdot \sin(\varphi_2 - \varphi_3) \end{cases} \tag{14}$$

$$\begin{cases} F_T = F_n^I + F_{\tau_C}^I = F_n \cdot \cos(\varphi_2 - \varphi_3) + \\ F_{\tau_C} \cdot \sin(\varphi_2 - \varphi_3) = F_m \cdot \sin(\varphi_2 - \varphi_1) \cdot \cos(\varphi_2 - \varphi_3) \\ + \frac{a}{b} \cdot F_m \cdot \cos(\varphi_2 - \varphi_1) \cdot \sin(\varphi_2 - \varphi_3) \\ = F_m \cdot \begin{bmatrix} \sin(\varphi_2 - \varphi_1) \cdot \cos(\varphi_2 - \varphi_3) + \\ \frac{a}{b} \cdot \cos(\varphi_2 - \varphi_1) \cdot \sin(\varphi_2 - \varphi_3) \end{bmatrix} \end{cases} \tag{15}$$

$$\begin{cases} F_U = F_T \cdot \sin\varphi_3 \\ F_R = F_T \cdot \cos\varphi_3 \end{cases} \tag{16}$$

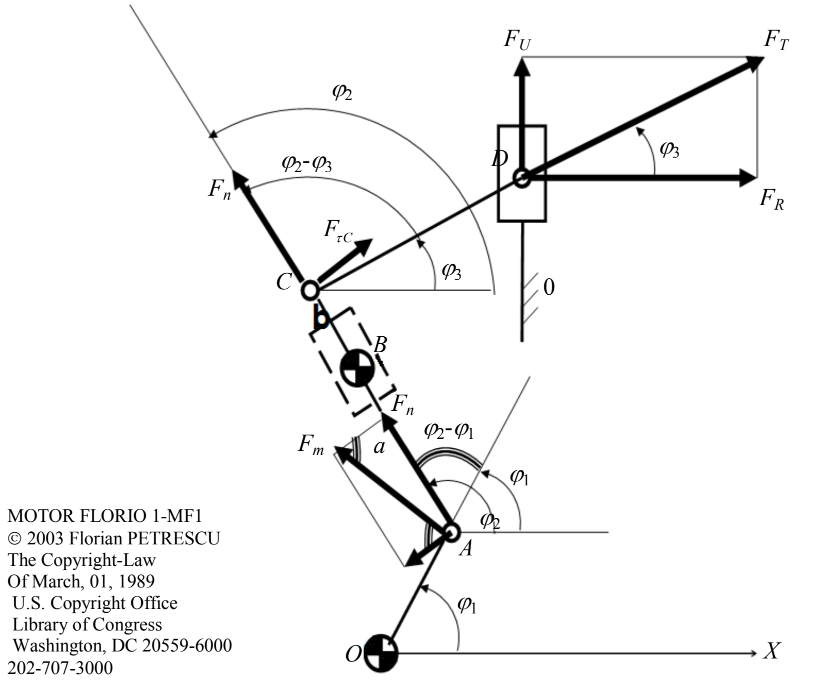

Fig. 4: The MF1 distribution of forces, when the mechanism works like a steam roller

$$\left\{ F_U = F_m \cdot \sin\varphi_3 \cdot \begin{bmatrix} \sin(\varphi_2-\varphi_1)\cdot\cos(\varphi_2-\varphi_3) \\ +\frac{a}{b}\cdot\cos(\varphi_2-\varphi_1)\cdot\sin(\varphi_2-\varphi_3) \end{bmatrix} \right. \tag{17}$$

$$\left\{ v_U = v_m \cdot \begin{bmatrix} \cos\varphi_1 - \dfrac{l_2\cdot\cos\varphi_2\cdot\cos(\varphi_1-\varphi_2)}{a} \\ l_0\cdot\cos\varphi_1\cdot\sin(\varphi_3-\varphi_2) \\ +\dfrac{+b\cdot\cos(\varphi_1-\varphi_2)\cdot\cos(\varphi_3-\varphi_2)}{a}\cdot\cos\varphi_3 \end{bmatrix} \right. \tag{18}$$

$$\left\{ \begin{array}{l} \eta_{iC} = \dfrac{F_U\cdot v_U}{F_m\cdot v_m} = \sin\varphi_3\cdot\begin{bmatrix} \sin(\varphi_2-\varphi_1)\cdot\cos(\varphi_2-\varphi_3) \\ +\frac{a}{b}\cdot\cos(\varphi_2-\varphi_1)\cdot\sin(\varphi_2-\varphi_3) \end{bmatrix}\cdot \\ \begin{bmatrix} \cos\varphi_1 - \dfrac{l_2\cdot\cos\varphi_2\cdot\cos(\varphi_1-\varphi_2)}{a} + \\ \dfrac{l_0\cdot\cos\varphi_1\cdot\sin(\varphi_3-\varphi_2)+b\cdot\cos(\varphi_1-\varphi_2)\cdot\cos(\varphi_3-\varphi_2)}{a} \\ \cdot\cos\varphi_3 \end{bmatrix} \end{array} \right. \tag{19}$$

It can determine the instant mechanical yield when the mechanism works as a motor, if one determines the forces distribution from the motor piston to the motor crank (Fig. 5); see relations (20-25):

$$\begin{cases} F_N = F_m\cdot\sin\varphi_3 \\ F_R = F_m\cdot\cos\varphi_3 \end{cases} \tag{20}$$

$$\begin{cases} F_n = F_N\cdot\cos(\varphi_2-\varphi_3) \\ F_{\tau_C} = F_N\cdot\sin(\varphi_2-\varphi_3) \end{cases} \tag{21}$$

$$F_{\tau_A} = \frac{b}{a}\cdot F_{\tau_C} = \frac{b}{a}\cdot F_m\cdot\sin\varphi_3\cdot\sin(\varphi_2-\varphi_3) \tag{22}$$

$$\begin{cases} F_{u1} = F_n\cdot\sin(\varphi_1-\varphi_2) \\ F_{u2} = -F_{\tau_A}\cdot\cos(\varphi_1-\varphi_2) \end{cases} \tag{23}$$

$$\left\{ \begin{array}{l} F_u = F_{u1}+F_{u2} = F_m\cdot\sin\varphi_3\cdot \\ \cdot\begin{bmatrix} \cos(\varphi_2-\varphi_3)\cdot\sin(\varphi_1-\varphi_2) \\ -\frac{b}{a}\cdot\sin(\varphi_2-\varphi_3)\cdot\cos(\varphi_1-\varphi_2) \end{bmatrix} \end{array} \right. \tag{24}$$

$$\left\{ \begin{array}{l} N = -\sin\varphi_3\cdot\begin{bmatrix} \cos(\varphi_2-\varphi_3)\cdot\sin(\varphi_1-\varphi_2) \\ -\frac{b}{a}\cdot\sin(\varphi_2-\varphi_3)\cdot\cos(\varphi_1-\varphi_2) \end{bmatrix} \\ n = \cos\varphi_1 + \cos\varphi_3\cdot \\ \dfrac{l_0\cos\varphi_1\sin(\varphi_3-\varphi_2)+b\cos(\varphi_1-\varphi_2)\cos(\varphi_3-\varphi_2)}{a} \\ -\dfrac{l_2\cos\varphi_2\cos(\varphi_1-\varphi_2)}{a} \\ \mu_{iM} = \dfrac{N}{n} \end{array} \right. \tag{25}$$

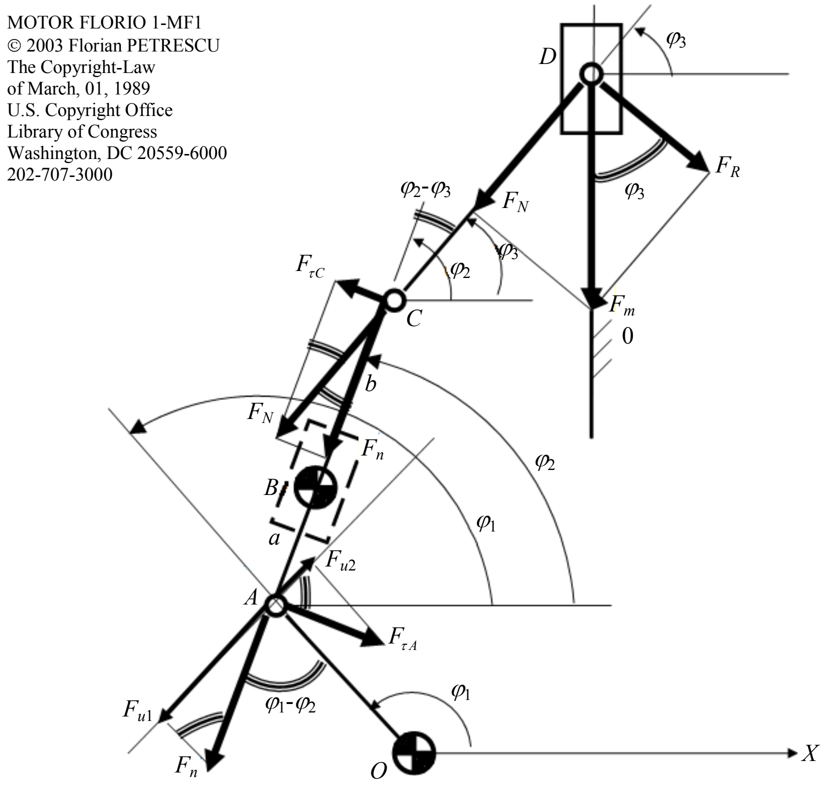

Fig. 5: The MF1 distribution of forces, when the mechanism works like a motor

The dynamic yield of the mechanism is the same at any moment (when the motor mechanism works as a steam roller and when it's working as a engine). It can be calculated approximately with the relationship (26). It can calculate the exactly instantly dynamic yield of the motor mechanism, if one takes in use the dynamic velocities (in this situation the distribution of the velocities is the same as the distribution of forces), the relations (27-29):

$$\begin{cases} \mu_i^D = \mu_{iM}^D = \eta_{iC}^D = \sin^2\varphi_3 \cdot \sin^2\tau \\ with:\ \tau = 2\cdot\varphi_2 - \varphi_1 - \varphi_3 \end{cases} \tag{26}$$

$$\left\{ -\frac{F_u}{F_m} = \sin\varphi_3 \cdot \begin{bmatrix} \sin(\varphi_2-\varphi_1)\cdot\cos(\varphi_2-\varphi_3) \\ +\frac{b}{a}\cdot\sin(\varphi_2-\varphi_3)\cdot\cos(\varphi_2-\varphi_1) \end{bmatrix} \right. \tag{27}$$

$$\left\{ -\frac{v_u}{v_m} = \sin\varphi_3 \cdot \begin{bmatrix} \sin(\varphi_2-\varphi_1)\cdot\cos(\varphi_2-\varphi_3) \\ +\frac{a}{b}\cdot\sin(\varphi_2-\varphi_3)\cdot\cos(\varphi_2-\varphi_1) \end{bmatrix} \right. \tag{28}$$

$$\left\{ \mu_i^D = \sin^2\varphi_3 \cdot \begin{Bmatrix} \sin^2(\varphi_2-\varphi_1)\cdot\cos^2(\varphi_2-\varphi_3) + \\ \sin^2(\varphi_2-\varphi_3)\cdot\cos^2(\varphi_2-\varphi_1) + \\ \frac{a^2+b^2}{4\cdot a\cdot b}\cdot\sin\left[2\cdot(\varphi_2-\varphi_1)\right]\cdot\sin\left[2\cdot(\varphi_2-\varphi_3)\right] \end{Bmatrix} \right. \tag{29}$$

One determines now the dynamic motor velocity (30) and the dynamic motor acceleration of the piston (31):

$$\left\{ v_D^{Din} = l_1\cdot\omega_1\cdot\sin\varphi_3\cdot \begin{bmatrix} \sin(\varphi_2-\varphi_1)\cdot\cos(\varphi_2-\varphi_3) \\ +\frac{a}{b}\cdot\sin(\varphi_2-\varphi_3)\cdot\cos(\varphi_2-\varphi_1) \end{bmatrix} \right. \tag{30}$$

$$\left\{ a_D^{Din} = \begin{Bmatrix} \omega_3\cdot\cos\varphi_3\cdot \begin{bmatrix} \sin(\varphi_2-\varphi_1)\cdot\cos(\varphi_2-\varphi_3) \\ +\frac{a}{b}\cdot\cos(\varphi_2-\varphi_1)\cdot\sin(\varphi_2-\varphi_3) \end{bmatrix} \\ +\sin\varphi_3\cdot \begin{bmatrix} \cos(\varphi_2-\varphi_1)\cdot\cos(\varphi_2-\varphi_3)\cdot(\omega_2-\omega_1) \\ -\sin(\varphi_2-\varphi_1)\cdot\sin(\varphi_2-\varphi_3)\cdot(\omega_2-\omega_3) \\ -\frac{a}{b}\cdot\sin(\varphi_2-\varphi_1)\cdot\sin(\varphi_2-\varphi_3)\cdot(\omega_2-\omega_1) \\ +\frac{a}{b}\cdot\cos(\varphi_2-\varphi_1)\cdot\cos(\varphi_2-\varphi_3)\cdot(\omega_2-\omega_3) \\ +\frac{\dot{a}}{b}\cdot\cos(\varphi_2-\varphi_1)\cdot\sin(\varphi_2-\varphi_3) \\ +\frac{a\cdot\dot{a}}{b^2}\cdot\cos(\varphi_2-\varphi_1)\cdot\sin(\varphi_2-\varphi_3) \end{bmatrix} \end{Bmatrix} \cdot l_1\cdot\omega_1 \right. \tag{31}$$

Internal combustion engines carry us every day and doing this for 150 years. Although they started to be partially replaced by other engines (eg electric) the engines type diesel or Otto still remain the most used and loved.

Even if you would like immediate replacement of all vehicles equipped with internal combustion engines with electric motors, the work would not be possible than in 40-50 years, due to higher fleet reached today, which already exceeds one billion cars.

In current conditions, the only way to further reduce pollution caused by the huge car park is to further improve the characteristics of these engines and incur new rules to limit their pollution. For this reason we want to present in this study a new model of internal combustion engine, capable of running with reduced exhaust emissions.

When the motor constructive parameters values are different from the usual used values, the dynamic motor speeds and the dynamic motor acceleration of the new motor piston (see equations 30-31), are not the same as the classical kinematics known values (see relations 8-11), (Fig. 6 and 7).

In this study was presented briefly a prototype internal combustion engine and the dynamic kinematics calculations.

In dynamic operation (Amoresano *et al*., 2013), a motor mechanism works so that cinematic speeds are aligned after forces direction, which are imposed in turn by the linkages of mechanism.

This phenomenon occurs in any mechanism on dynamic regimes, when the rotation speed of the crank is higher than 100 [rpm]. For exemplification one presents below this distribution to a usual engines which is working in four times (Fig. 8), (Petrescu and Petrescu, 2014a; 2014b; 2014c).

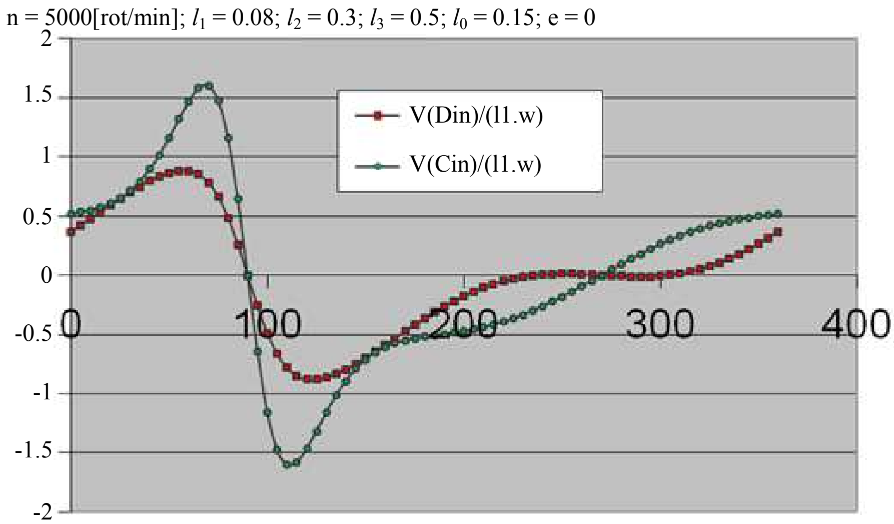

Fig. 6: The kinematical and dynamic velocities

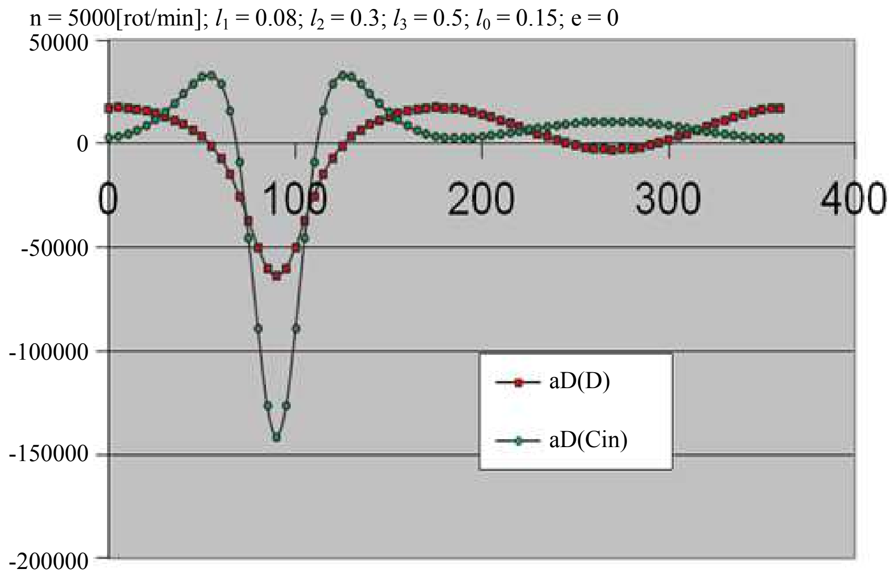

Fig. 7: The kinematical and dynamic accelerations

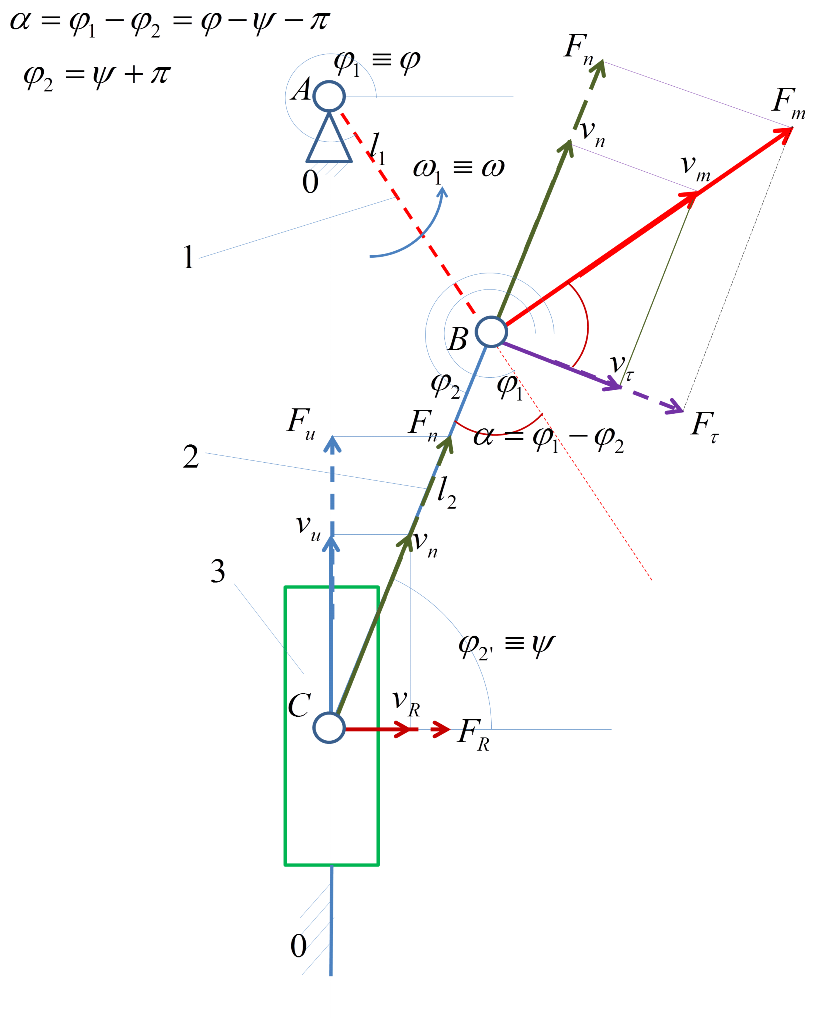

Fig. 8: The forces and velocities distribution in an engine mechanism, when it is operated of the crank (element 1)

Correct design of an internal combustion engine is made by lowering the ratio $\lambda = r / l$. Where r is the length of the crank and connecting rod length it is l. Stroke h must be and it as small as possible.

This goal is achieved by reducing the crank radius r. If we want to keep intact displacement (engine capacity) will have to grow the bore (R).

Modern engines (very high speed) will have an almost imperceptible race (stroke) and a great bore. The piston of such a motor will gain the appearance of a saucepan.

Conclusion

The paper presents the dynamic study of a triad in an original vision of the authors.

Was presented and an original engine model. This type of motor can improve the changes of gases and may decrease significantly the level of vibration, noises and emissions. In addition at this mechanism (of the new presented motor) and efficiency is higher.

These adjustments may be provided for some special dynamic calculation with an improved dynamic system, new created by authors.

Only any mechanisms have the same parameters for the classical and for the dynamic kinematics (gears, cams with plate followers).

To the presented motor mechanism the dynamic-kinematics is different from the classical-kinematics known, but when the constructive parameters are setting on normal values, the dynamic motor velocities and accelerations take the same values as the classical motor speeds and accelerations known.

In the presented article was showed a new model of an internal combustion engine, able to running with reduced exhaust emissions.

The new mechanism was designed and intended for industrial production.

As long as we produce electricity and heat by burning fossil fuels is pointless to try to replace all thermal engines with electric motors, as loss of energy and pollution will be even larger. However, it is well to continuously improve the thermal engines, to reduce thus fuel consumption.

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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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