COMPARATIVE DYNAMIC SIMULATIONS OF TWO VARIANTS OF A CRANK-ROCKER LINKAGE

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Key words: degree-of-freedom, planar linkage, mechanisms' classical model, flexi-block.

Abstract: The paper presents comparatively the dynamic responses of two variants of a given linkage: the classical four-bar mechanism and the five-DOF planar linkage, in which the connecting rod is fitted with rubber joints (flexi-blocks). There are briefly presented the structural and dynamic modelling of these linkages by means of the mechanisms' classical model. Then, for the two variants, fitted with motor-reducers and producers, the dynamic responses are established.

1. INTRODUCTION

The increase of durability represents an important task in the mechanical transmissions' design. One way to ensure superior performances consists in using optimized transmissions, in which the dangerous *statical undetermined* or *hyperstatical* constraints (which tend to block the mechanism) are eliminated; this desideratum can be achieved replacing some of the mechanism's joints through appropriate joints of higher mobility and/or introducing some adequate supplementary joints. Thus, in the case of a planar crank-rocker linkage from Fig.1,a (used in the extraction of grained materials from silages) the elimination of the hyperstatical constraints can be made by the introduction of the supplementary joints E, F and G (Fig.1,b). From economical and constructive reasons, revolute joints with rubber core (flexi-blocks), like the elastic joints B and C (Fig.1,c) are frequently used instead of the joints E, F and G (Fig.1,b). The introduction of elastic joints doesn't change the transmission's overall dimensions, but it has significant effects in the mechanism kinematical and dynamic modelling. The connecting rod fitted with the elastic joints B and C (Fig. 1,c) can be modelled through the planar kinematical chain from Fig.1,d.

The mechanism fitted with such a connecting rod can be *studied based on the mechanisms' classical model, if the springs and dampers from Fig.1,d are considered as entities of "motor/producer" type;* in the premise that the deviations, from the theoretical configuration, are null, after *isolation* of the mechanical system from its *motors* and *producers*, the planar mechanism from Fig.1,e is obtained.

After a concise dynamic models' presentation, in the paper there are comparatively analysed the dynamic responses of the two variants of a crank-rocker linkage:

a. a crank-rocker mechanism (Fig. 1,a) with rigid bodies and classical joints, and
b. the mechanism in which the links of the connecting rod to the crank and rocker are modelled through flexi-blocks with longitudinal and transversal deformations, against the connecting rod (Fig. 1,e).

The classical mechanism has the degree-of-freedom M=1 and L=2 external links, designated through the driving joint A and the resistant joint D (Fig.1,a). Therefore, this mechanism has:

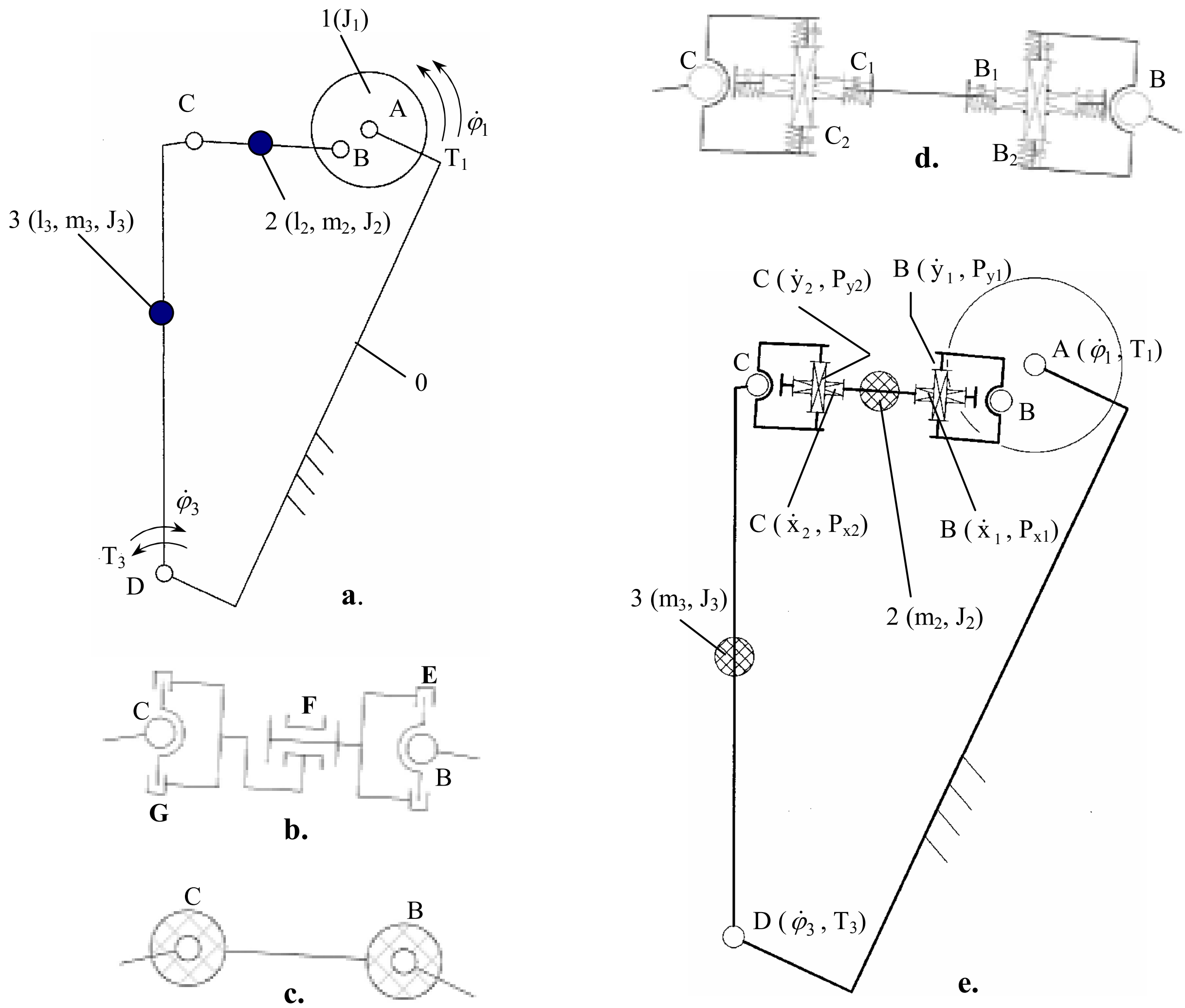


Fig. 1 *The crank-rocker mechanism: a) the classical variant, b) the isostatical variant (the connecting rod), c) the connecting rod fitted with elastic joints, d) the connecting rod fitted with springs and dampers on two directions, e) the mechanism with flexi-blocks*

a1) M=1 => one independent external motion (for instance: φ_1) and L-M=1 => a transmission function for motions: $\varphi_3 = \varphi_3(\varphi_1) \Rightarrow \omega_3, \varepsilon_3$;

a2) M=1 => one transmission function for moments, e.g.: $T_1 = T_1(\varphi_1, T_3)$.

Unlike the classical crank-rocker linkage, the use of flexi-blocks brings an important constructive simplification, but increases the mechanism degree-of-freedom (Fig.1,e): the degree-of-freedom becomes M=5 and the L=6 external links are designated by the joints A, B_1, B_2, C_1, C_2 and D, with the external parameters $(\dot{\varphi}_1, T_1)$,$(\dot{\varphi}_3, T_3)$, $(\dot{x}_1, P_{x1})$, $(\dot{y}_1, P_{y1})$, $(\dot{x}_2, P_{x2})$ and $(\dot{y}_2, P_{y2})$, respectively. Therefore, the mechanism from Fig.1,e has:

b1) M=5 independent external motions and, implicitly, L-M=1 => one transmission function for motions: $\varphi_3 = \varphi_3(\varphi_1, x_1, x_2, y_1, y_2) \Rightarrow \omega_3, \varepsilon_3$;

b2) M=5 transmission functions for moments and forces: $T_1 = T_1(\varphi_1, x_1, x_2, y_1, y_2, T_3)$, $P_{x1} = P_{x1}(\varphi_1, x_1, x_2, y_1, y_2, T_3)$, $P_{x2} = P_{x2}(\varphi_1, x_1, x_2, y_1, y_2, T_3)$, $P_{y1} = P_{y1}(\varphi_1, x_1, x_2, y_1, y_2, T_3)$, $P_{y2} = P_{y2}(\varphi_1, x_1, x_2, y_1, y_2, T_3)$.

The establishment of the motion function relies on the development of the relations: BC = constant, for the first case (Fig.1,a), and $BC = BC(\varphi_1, x_1, x_2, y_1, y_2)$, for the second case (Fig.1,e).

The transmission functions for moments and forces were established using the *Lagrange*'s equations of second sort.

2. THE DYNAMIC RESPONSE'S MODELLING

The linkage's dynamic responses can be now obtained coupling the mechanism to its motors and producers. For each of the two electromechanical systems (see Fig.1,a and e), after processing the 2L equations' system (with L mechanism's equations + L external links' equations = 2L equations), M motion equations are obtained, which can be solved using the Matlab-Simulink software. The Simulink schemes for the analysed cases are presented in Fig.2 and 3, allowing to establish the variations in time of the specified unknowns: φ_1, φ_3 ; T_1, T_3 for the classical mechanism (see Fig.1,a) and, φ_1, φ_3, x_1, x_2, y_1, y_2; T_1, T_3, P_{x1}, P_{x2}, P_{y1}, P_{y2}, for the linkage with flexi-blocks (see Fig.1,e), respectively.

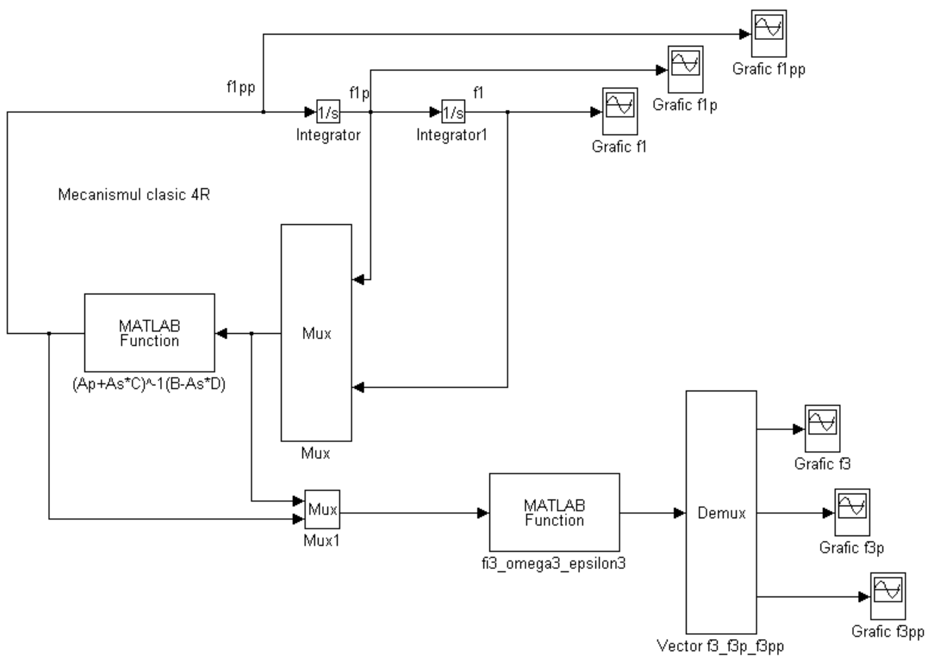


Fig. 2 *The Simulink scheme of the calculating programs for the classical mechanism from Fig.1,a*

The diagrams from Fig.4, 5 and 6 were obtained with the following numerical values (Fig.1):

- For both variants (Fig,1,a and e): AD = 1.246 [m], AB = 0.12 [m], CD = 1.18 [m], $\varphi_1 = [0, 2\pi]$ rad and for the classical variant (Fig.1,a): BC = 0.4 [m] = constant;
- The masses: the connecting rod m_2 = 15 [kg], the rocker m_3 = 75 [kg]; the masspoints of the connecting rod and rocker are situated in the middle of each element: BC/2 and CD/2 respectively;
- The inertia moments: the crank J_1 = 1 [kg m2], the connecting rod J_2 = 0,075 [kg m2], relative to the masspoint, the rocker J3 = 0,15 [kg m2], relative to the centre of rotation D;
- The springs rates (Fig.1,d): $k_{x1} = k_{y1} = -1243{,}55.10^3$ [N/m], $k_{x2} = k_{y2} = -1732{,}5.10^3$ [N/m];
- The rubber dampers constants (Fig.1,d): $k_{vx1} = k_{vy1}$ = - 500 [Ns/m], $k_{vx2} = k_{vx2}$= -750 [Ns/m].

The variations in time of the angular speeds, accelerations and moments of the rocker from the two variants of the crank-rocker linkage are represented in Fig. 4; the variations of the displacements from flexi-blocks x_1, x_2, y_1 and y_2, speeds $\dot{x}_1, \dot{x}_2, \dot{y}_1, \dot{y}_2$ and accelerations $\ddot{x}_1, \ddot{x}_2, \ddot{y}_1, \ddot{y}_2$ are represented in Fig. 5 and 6.

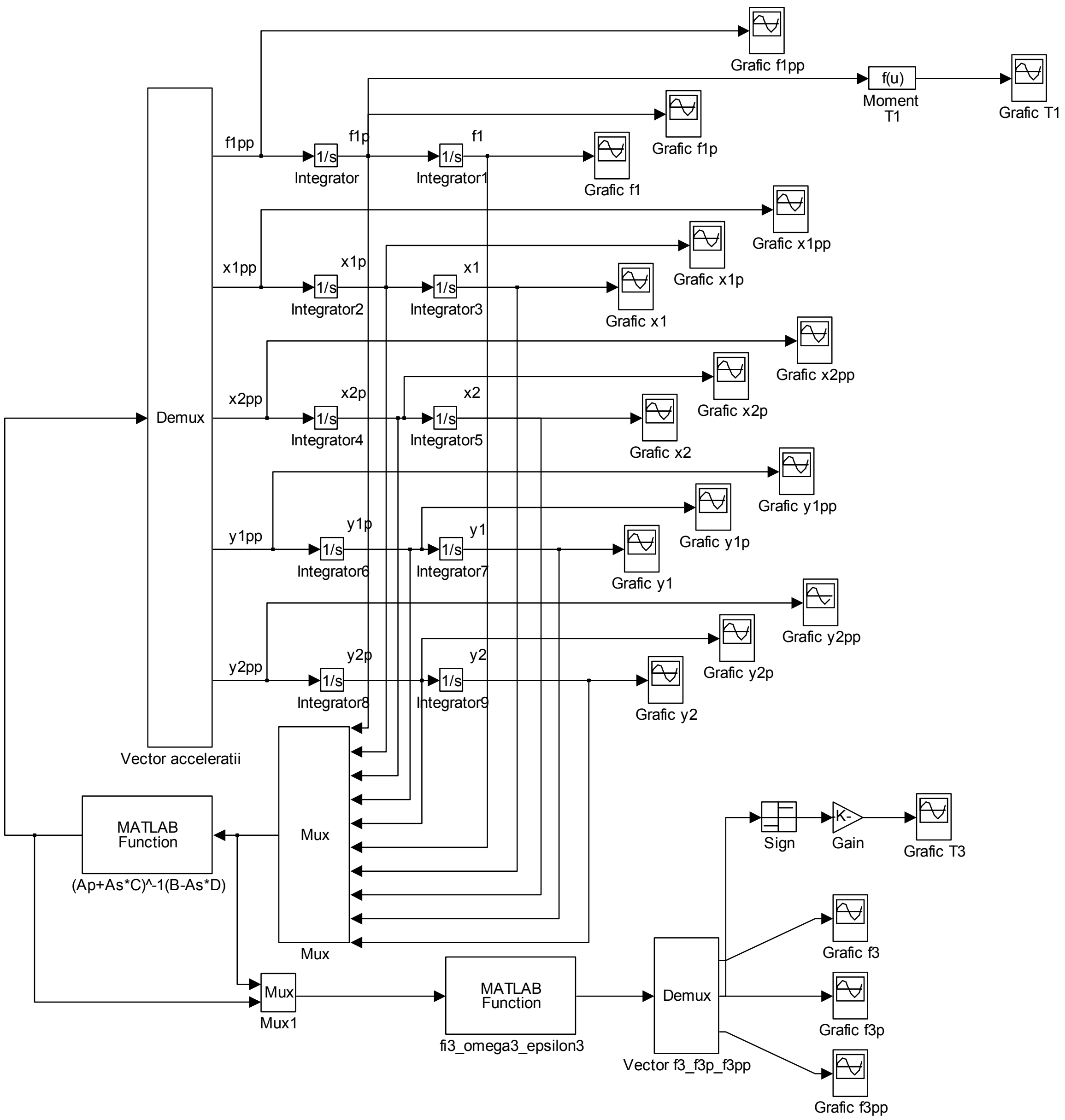
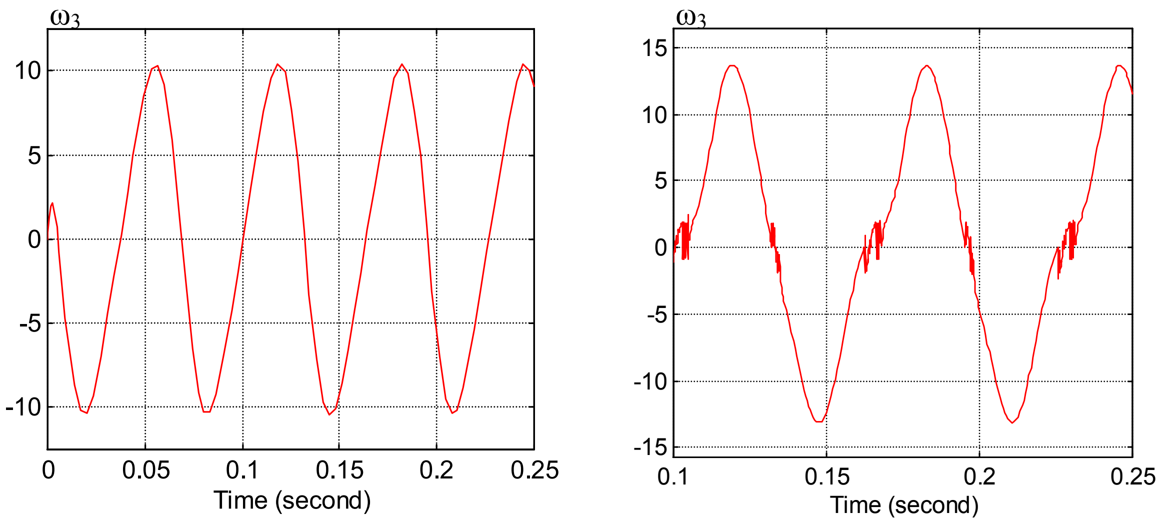


Fig. 3 *The Simulink scheme of the calculating programs for the mechanism from Fig.1,e*

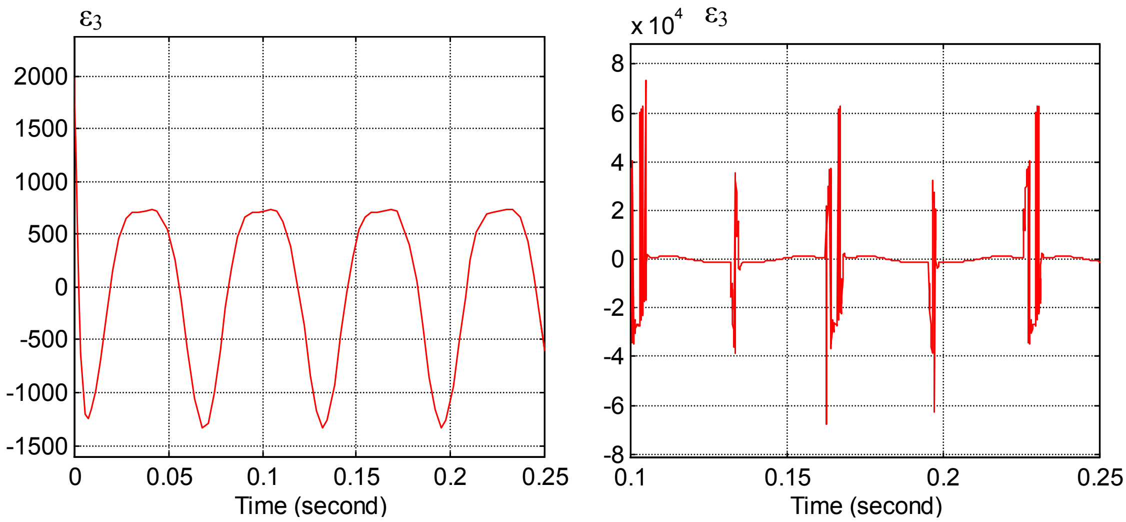
The diagrams from Fig. 4, a, b, c highlight the influence of the flexi-blocks on the rocker motion, against the motion in the classical mechanism. It can be observed that the elastic deformations from the flexi-blocks (x_i and y_i) have relativ small influences on the rocker speed ω_3, acceleration ε_3 and moment T_3; these parameters have, in the both cases, a variation period about 0,075 [s].

The flexi-blocks' influences consist mainly in the interference of the amortized vibrations at the angular races' extremities.

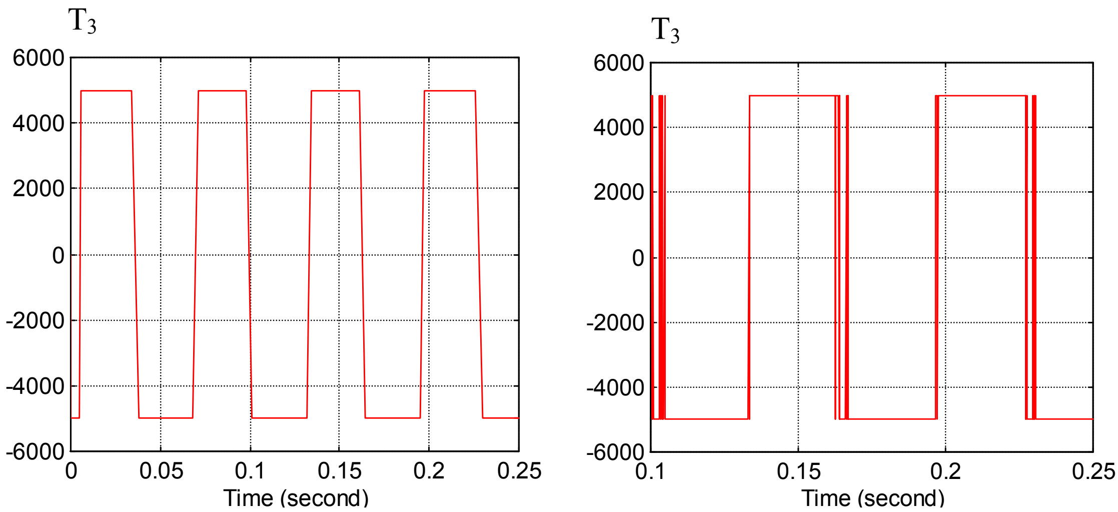
The diagrams from Fig. 5 illustrate, comparatively, the deformations, speeds and accelerations from the longitudinal springs placed in joints B and C (see Fig.1,d); these variations have the same period about 0,075 [s]. But the deformation x_1 from joint B (Fig. 5, a) is about ten times bigger than x_2 from joint C (Fig. 5, a_1) due to the inertial effect of the connecting rod and the forces that act in the flexi-blocks. Also, the speed $\dot{x}_1$ (Fig. 5, b) of the spring from joint B has a continuos variation, proving that the spring is deformed continuosly, while the longitudinal spring from C is deformed very quikly, with a high value



a.



b.



c.

Fig.4 *The variations of the angular speeds (a), angular accelerations (b) and torques (c) for the two variants of the crank-rocker mechanism*

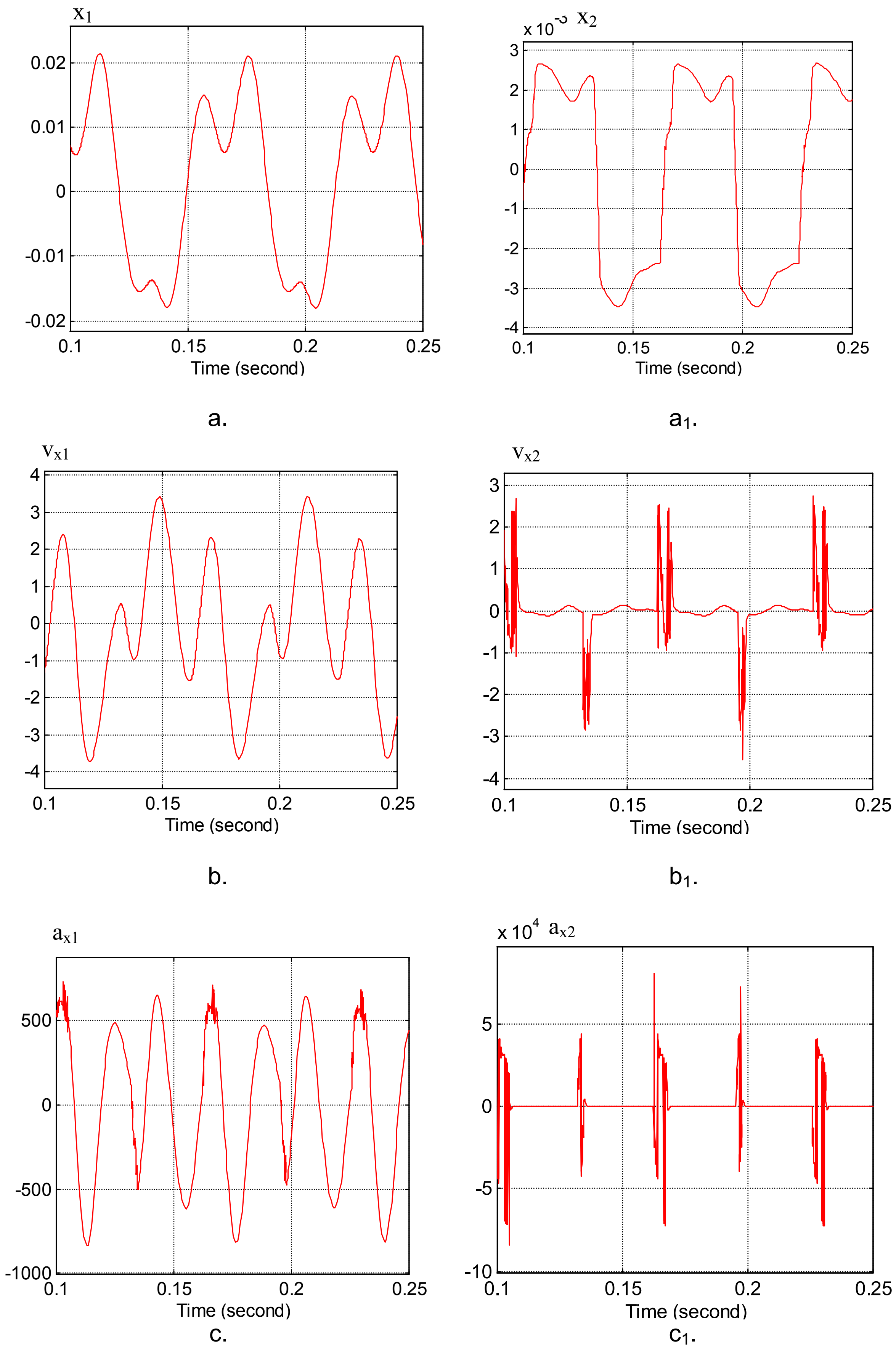


Fig. 5 *The variations of the longitudinal displacements (a,a_1), speeds (b,b_1) and accelerations (c,c_1) for the two variants of the crank-rocker mechanism*

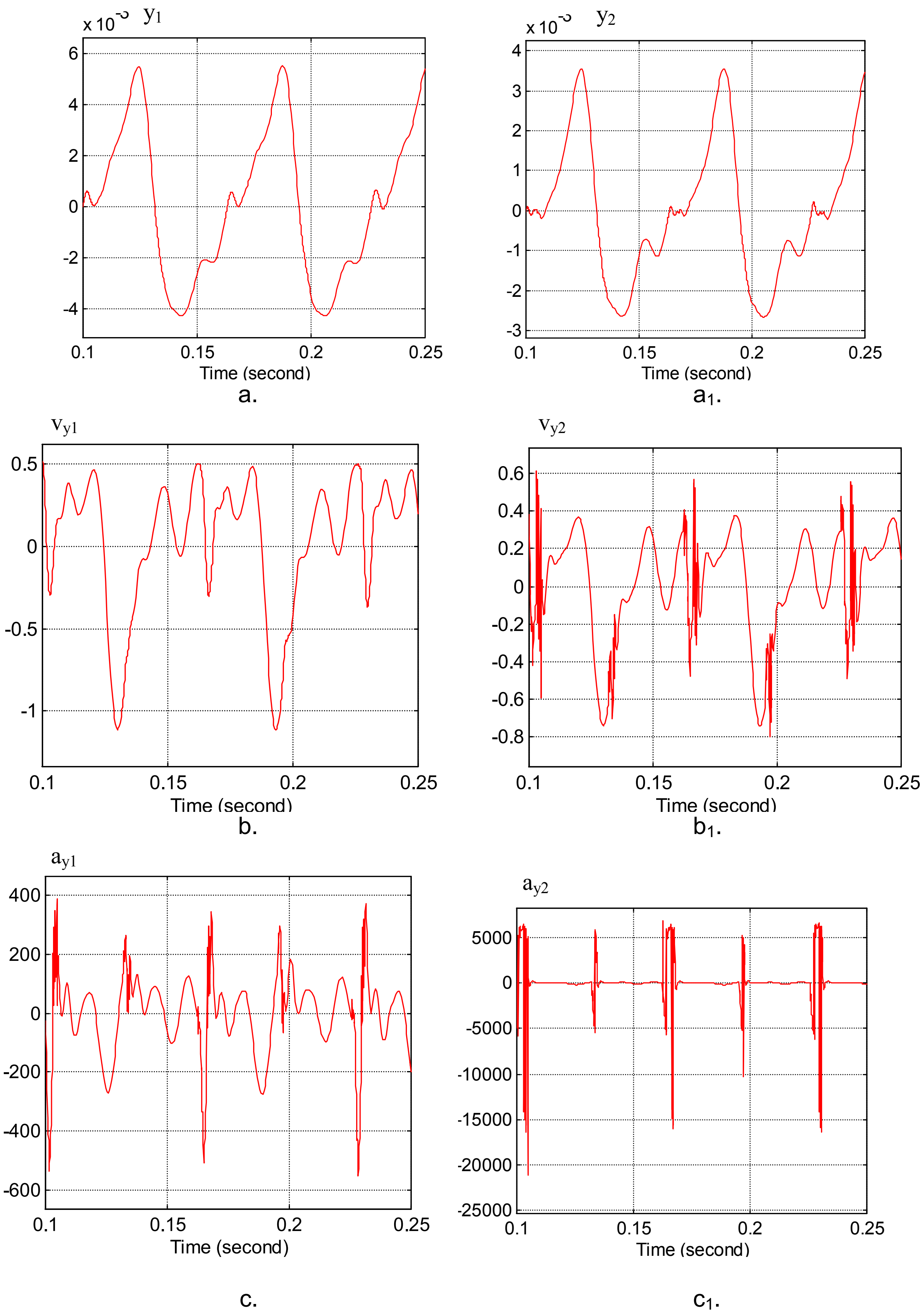


Fig. 6 *The variations of the transversal displacements (a,a_1), speeds (b,b_1) and accelerations (c,c_1) for the two variants of the crank-rocker mechanism*

of the angular acceleration and then remains deformed till next race end (periods of time in which the spring speed and acceleration remain practically null).

In Fig. 6 there are illustrated the deformations, speeds and accelerations from the transversal springs placed in joints B and C (Fig.1,d). The deformation y_1 in joint B (Fig. 6, a) is about two times bigger than the deformation y_2 from joint C (Fig. 6, a_1), but the two deformations take place aproximately in the same time. The diagrams of the angular speeds $\dot{y}_1$ and $\dot{y}_2$ (Fig. 6, b and b_1) and accelerations $\ddot{y}_1$ and $\ddot{y}_2$ (Fig. 6, c and c_1) highlight the behaviour of the transversal springs from joints B and C with respect to the time: the speed $\dot{y}_1$ (Fig. 6, b_1) and acceleration $\ddot{y}_1$ (Fig. 6, c_1) have a continuos variation, while the second transversal spring is deformed similarly, but a little more quikly (see the accelerations' diagrams from Fig. 6).

3. CONCLUSIONS

The use of flexi-blocks, as a solution of mechanisms' optimization, brings an important constructive simplification and, implicitly, a significant economical efficiency, but also, an *increase* of the mechanism *degree-of-freedom*.

The classical model of mechanisms can be also used in the study of mechanisms with flexi-blocks, if these are taken as entities of *motor/producer* type (i.e. as mechanism's *external links*).

For the establishment of the dynamic response of a mechanism with flexi-blocks, the mechanism isolated from its motors and producers is firstly analyzed and, afterwards, it is re-coupled to them.

The kinematical and dynamical modelling of the transmissions with elastic joints or elements can not be decoupled: the displacements from the mechanism joints depend on the forces and moments that act on the mechanism elements. Therefore, the mechanism can be finally analysed only together with its motors and producers.

There are some differences in the behaviour of the springs placed in joints B and C, which are due to the forces that act in the flexi-blocks and to the inertial effect of the connecting rod. Thus, the longitudinal spring from joint C is deformed very quickly and remains deformed till next race end, while the springs from joint B are continuously deformed.

The methodology presented in this paper on the example of a planar mechanism, can be directly applied to spatial mechanisms, too; thus, the study of the dynamic effects of the deviations from the theoretical model becomes possible.

References

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