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ON THE ELIMINATION OF MECHANISMS' STRUCTURAL DEFECTS

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Abstract: One of mechanical transmissions' optimization goals, used to increase their reliability, consists in removing the structural defects that are due to the hyperstatical constraints. These constraints become active when manufacturing or assembling deviations appear, trying to block up the transmission, or even, at limit, to make impossible their assembling. The modeling of mechanisms with structural defects and the numerical simulation of the effects of deviations on the transmission functions and on the closed-loop kinematical chain behavior are presented in this paper based on a representative example.

1. INTRODUCTION

According to the prerequisites of the mechanism fundamental structural model, the elements are considered non-deformable and the joints ideal, linear and bilateral, the manufacturing technology perfect and the materials strength unlimited. In these theoretical conditions, when the elastic and thermal deformations are considered null and friction is non-existent, the hyperstatical constraints don't influence the motions and forces transmission. But in real conditions, the mechanical transmission's deviations, due to its manufacturing and assembling, are unavoidable. Generally, the hyperstatical constraints don't affect in a negative way the mechanism good functioning and life cycle, if the deviations from its theoretical configuration are small enough. If these deviations exceed certain limits, the hyperstatical constraints become *structural defects*, as they tend to overstress the kinematical chain, to block up the mechanism or, at limit, to make assembling impossible.

A main direction in increasing the reliability is referring either to the **elimination** of structural defects which tend to block up the transmission and introduce supplementary stresses, hardly reducing their life-cycle, or to the **reduction** of these constraints' negative effects, by making a compromise between the optimization costs and their effects on the transmission reliability.

An intuitive method for the structural modeling and testing of deviations effects on the transmission functions and mechanisms behavior is presented in this paper; the method uses in the structural modeling the rank of a system of equations that is described by constraints, simplifying, thus, the mathematical apparatus used in results interpretation used in literature [1,2]. The modeling is presented on the base of a representative example: a four-bar mechanism from an extractor mechanism used in grained materials extraction from silages – Fig. 1 (formed by aggregating four one-loop mechanisms); in real assembling conditions, the mechanism is characterized by relatively high deviations that can lead to the breakage of worm 11 and, therefore, to a relatively reduced life-cycle.

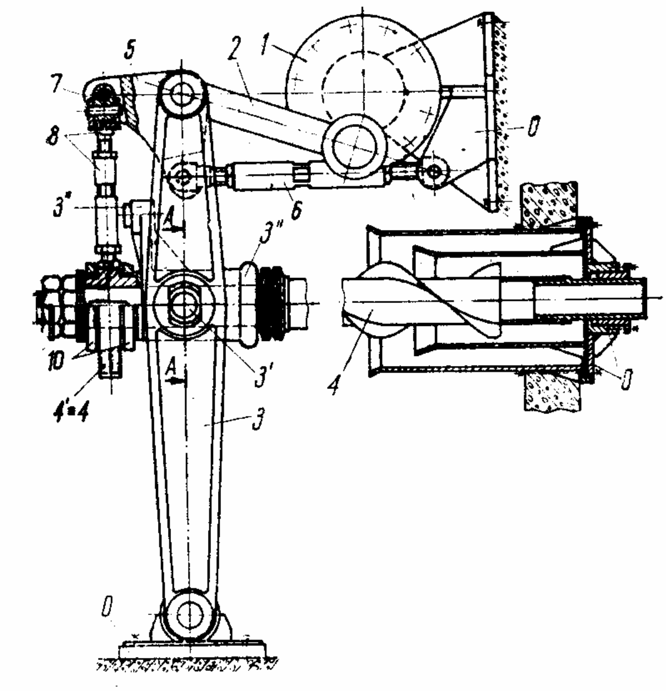

Fig. 1 *The mechanism used in grained materials extraction*

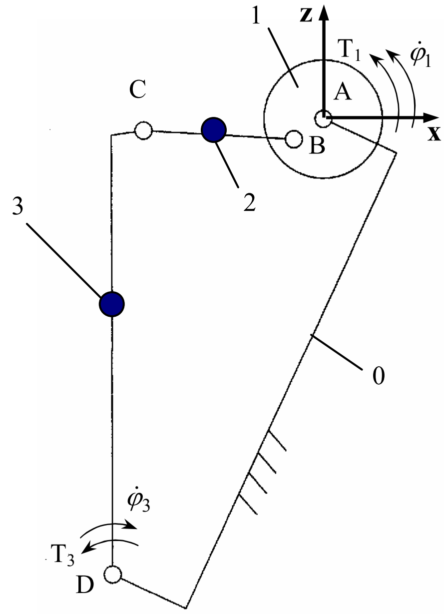

Fig. 2. *Structural diagram of the 4R mechanism*

2. STRUCTURAL MODELLING OF THE 4-BAR MECHANISM

In given constructive, functional and technological conditions, the elimination of structural defects from mechanisms can be done based on the following algorithm [3,4,5]:

- The structural parameters are established on the mechanism's theoretical structural model;
- The passive kinematical constraints and the theoretical solutions for eliminating them from the mechanism's theoretical model are identified;
- In terms of the deviations from the structural model given by the real functioning conditions, the passive kinematical constraints that become structural defects are identified; the rational ways of eliminating them are then selected.

The previous algorithm is exemplified on a one-loop mechanism of 4R type (Fig. 2), part of an extractor used in silages (Fig. 1). In theoretical conditions, the axes of joints A, B, C and D are parallel, the clearances and frictions inside the joints are null, the mechanism elements are considered non-deformable and with a perfect technological processing etc. In this case, for establishing the degree of freedom and the structural defects of the considered mechanism, the algorithm can be applied [5]:

- for the identification of the redundant constraints from the one-loop kinematical chain, the frame 0 of the closed chain is broken into two parts (0 and 4); the independent motions between the extremal elements are established $(f_{4,0}) = (v_x, \omega_y, v_z) \Rightarrow f_{4,0} = 3$; then, the degree of constraint inlaid by the open chain between the extremal elements 4 and 0 is established: $c^* = c_{4,0} = 6 - f_{4,0} = 6 - 3 = 3 \Rightarrow$ 3 constraints of equations: $\omega_x = 0$; $\omega_z = 0$; $v_y=0$; these constraints become *redundant* after 4 and 0 become one piece again ($4 \equiv 0$).
- the degree of statical indetermination S of the one-loop mechanism, further called the degree of hyperstaticity, is equal to the number of kinematical redundant constraints: $S = c^* = c_{4,0} = 3 \Rightarrow$ 3 *statically undetermined constraints*: $\omega_x = 0$, $\omega_z = 0$, $v_y = 0$.

- these constraints' elimination can be done by introducing the mobilities ω_x , ω_z , v_y; an example: introduction of three revolute joints in the mechanism (see Fig. 3): joint F introduces a passive mobility among x axis, while joints E and G, with the axes parallel to z, insert the passive motions ω_z and v_y. => $f_{4,0}$ = 6 and, implicitly, $c^* = c_{4,0} = 0$ *hyperstatical constraints* => the mechanism (see Fig. 3) is statically determined.
- the structural defects are eliminated by inserting the mobilities that are indicated by the equations of hyperstatical constraints. Thus, the statically undetermined mechanism (S > 0) becomes isostatical (S =0) (Fig. 2).

3. NUMERICAL SIMULATION

In order to identify the effects of the deviations on the transmission functions and on the closed kinematical chain behavior, a program for testing the influence of the deviations from the mechanism planar configuration is presented.

The program is built using Maple software, and is intended to establish:

a. the influence of the deviations from the planar configuration, on the angular displacements from joints E, F and G; when structural deviations appear, the passive motions from joints E, F and G become active and the 4R mechanism becomes a spatial mechanism of 7R type;
b. the deviations' influence on the pre-tensioning of the hyperstatical mechanism (S=3), through the angular displacements from joints E, F and G, which are considered as replaced by twistable elastic elements; therefore, the pre-tensioning moments can be modeled as products between a modulus of elasticity and the angular displacements of joints E, F, G, which were previously established.

In order to control the deviations, three distinct joints α, β and Δy (Fig. 4) are inserted in the considered mechanism (α allows a rotation around x, β - around z and Δy – a translation along y); the joints allow the introduction of angular / linear displacements that model the deviations from the planar configuration (after moving with one angular / linear step in each of the joints used for adjustment, the respective joint is considered frozen).

Different values, separately and combined, are given to the displacements from the adjustment joints and their effects on the parameters established at point A are numerically analyzed.

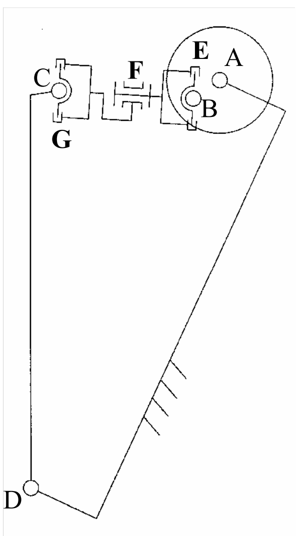

Fig. 3. *Structural diagram of the isostatic mechanism*

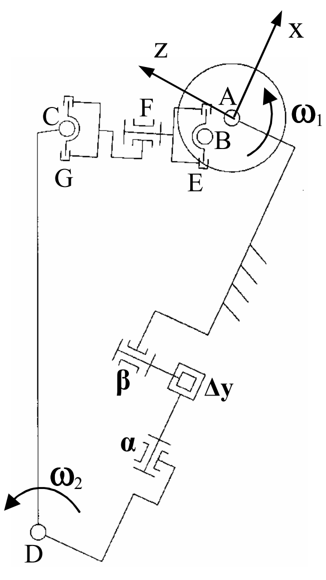

Fig. 4. *Structural diagram of the isostatic mechanism with adjustment joints*

The previously mentioned program is run with the following numerical values for the dimensions of the mechanism elements:

L_0=1.246 m, AB=0.12 m, CD=1.18 m, BC=0.4 m and φ_1 = [0, 2π] rad.

The deviations are introduced in the mechanism, through the adjustment joints α, β and Δy, with the following range of variation: $\alpha, \beta \in [-3^0, +3^0]$, $\Delta y \in [-0.12\,\text{m}, +0.12\,\text{m}]$. Firstly, the influence of each deviation on the angular displacements is numerically analyzed; afterwards, the influence of the combinations of different deviations on the same entities is analyzed. Same variations of the angular displacements are represented in Fig. 5.

In Fig. 5, a, b and c there are represented the variations of the angular displacements from the theoretically passive joints E, F and G, for deviations values equal to: $\alpha = -3^0,...,+3^0$, $\beta = \Delta y = 0$. Nearby, in Fig. 5, a_1, b_1 and c_1 there are represented the variations of the angular displacements from the passive joints E, F and G, for deviations values equal to: $\beta = -3^0,...,+3^0$, $\alpha = \Delta y = 0$.

From Fig. 2, a, b, c it can be observed that deviation α and the extreme angular displacements from joints E, F, G are increasing together; the maximum values appear in joint E and the minimum ones in joint G. From Fig. 5, a_1, b_1, c_1 it can be observed that deviation β has comparable influences on the displacements from joints E and G, but are backwards; the influence on the joint F displacement is very small (approximately 3 times smaller).

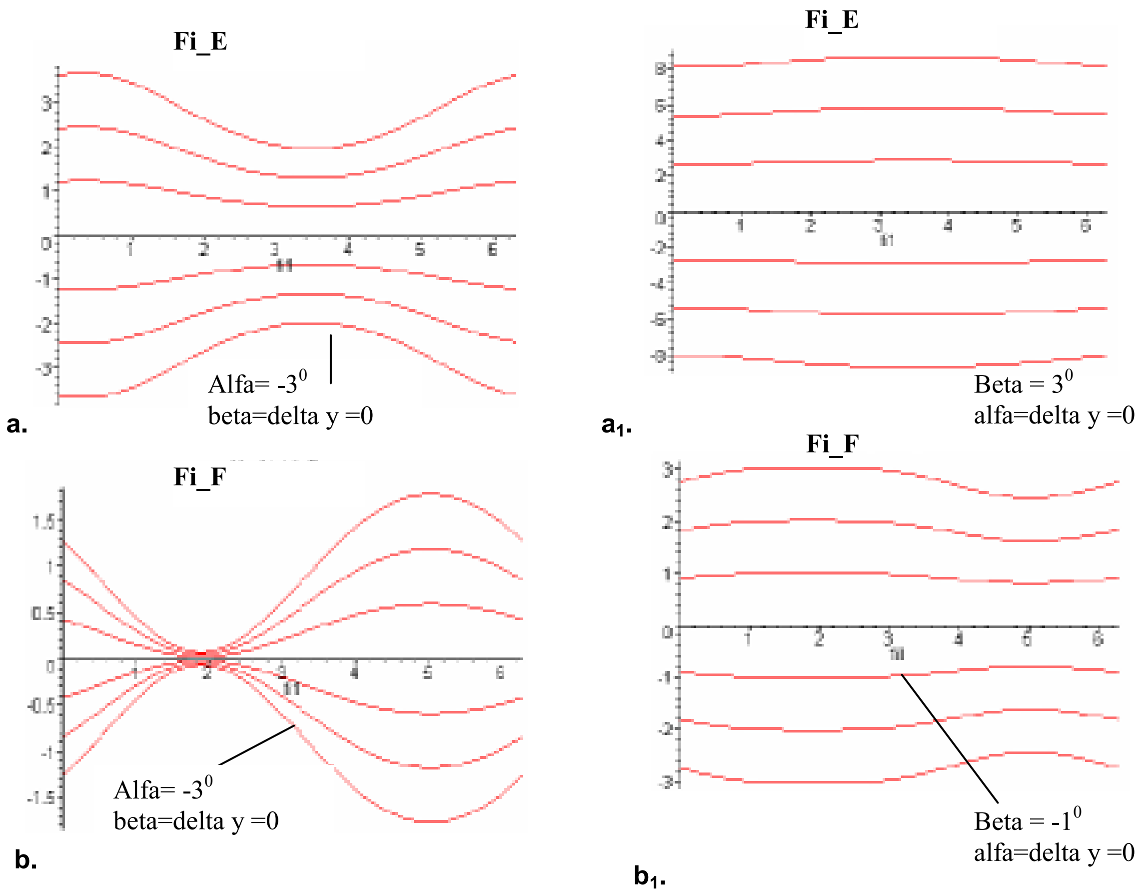

Fig. 5. *The influence of deviations on joints E, F and G*

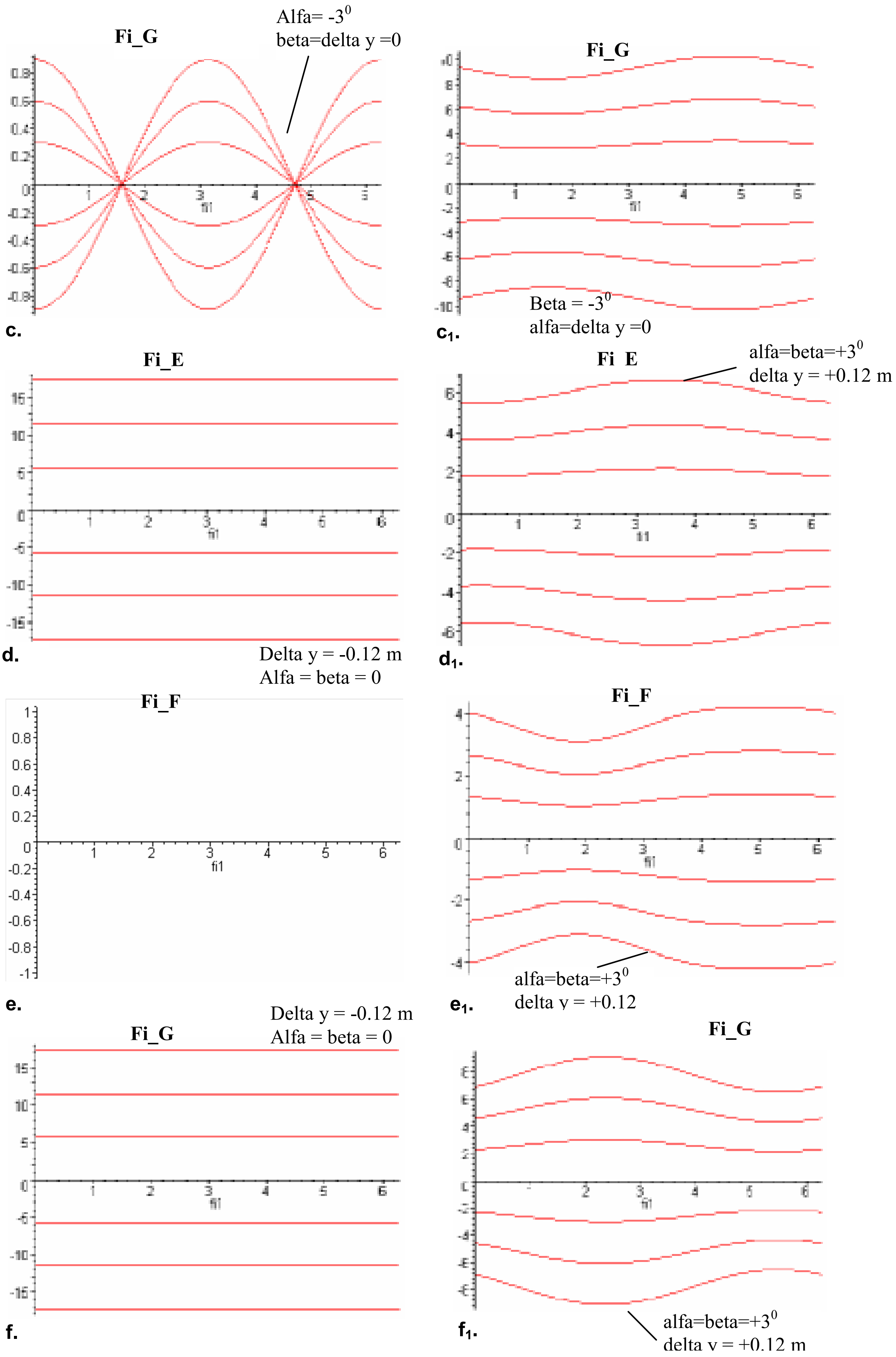

***Fig. 5.** The influence of deviations on joints E, F and G*

In Fig. 5, d, e and f there are represented the variations of the angular displacements from the passive joints E, F and G, for deviations values equal to: $\Delta y = -0.12,...,+0.12$ m, $\alpha = \beta = 0$. Nearby, in Fig. 5, d_1, e_1 and f_1 there are illustrated the variations of the same displacements for the sets of values $(\alpha = \beta)/\Delta y = -3^0/-0.12$, $-2^0/-0.08$, $-1^0/-0.04$, $0/0$, $+1^0/+0.04$, $+2^0/+0.08$, $+3^0/+0.12$.

From Fig. 5, d, e, f it can be observed that deviation Δy has no influences on the displacements from joint F, but the influences on the displacements from joints E, G are equal and of opposite direction. According to Fig. 5 d_1, e_1 and f_1, the influence of deviations α and β diminishes the influence of deviation Δy in joints E and G with approximately a half; instead, it introduces angular displacements in the middle joint F, equal approximately to a half of the other two joints displacements.

4. CONCLUSIONS

A method for identifying the hyperstatical constraints (possible structural defects) is presented in the paper. In order to identify the effects of the deviations on the transmission functions and on the closed kinematical chain behavior, a program for testing the influence of the deviations from the mechanism planar configuration is also presented.

Thus, the angular displacements from the theoretically passive joints E, F and G grow together with the increase of the deviations from the planar configuration: α, β and Δy. Under the premise that these joints are inexistent, pre-tensioning moments appear, moments that are equal to the product between the angular displacements and the elements modulus of elasticity. Obviously, due to the reduced elements elasticity, pre-tensioning moments of big values can appear in the closed chain; in these conditions, the mechanism durability is compromised, being necessary to insert supplementary adequate mobilities.

The modeling and numerical simulation highlight the necessity of an attentive numerical study about the influence of structural defects (α, β and Δy) in the design stage and, based on the obtained results, to identify the theoretically passive mobilities that are absolutely necessary and the optimal dimensioning of tolerances and adjustments.

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