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A COMPARATIVE ANALYSIS BETWEEN THE RIGID AND COMPLIANT JOINT MODELS FOR THE GUIDING SYSTEM OF THE CARS AXLES

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Abstract—The purpose of this work is to evaluate the effect of the deformability in the compliant joints on the static behavior of the guiding mechanisms used for the independent suspension of the cars' rear axle. The idea is to comparatively analyze the static behavior of the rigid model (with connections between bodies realized by spherical joints) relative to the real elastic model (with compliant joints - bushings), with the aim to establish if the rigid model assumption is useful for the static analysis. The comparative analysis between the compliant and rigid models is applied considering the general cases of guidance of the rear axle, with mono-mobile (by five points) and bi-mobile (by four points) guiding mechanisms. The study is conducted by using the MBS (Multi-Body Systems) software environment ADAMS.

Keywords—car axle, compliant model, guiding linkage, static analysis.

I. Introduction

A number of binary links of kinematic chains are used to guide the rear axle of a vehicle relative to the car body. A rear axle, relative to the car body, must have only two main motions: the roll motion (the rotation along the longitudinal axle of the chassis) and the vertical displacement. Between the guiding links (that connect the car to the rear axle) and the car body, there have to be bushings that are made by using elastic joints of rubber between an inner sleeve and an outer sleeve that are fixed to the axle, the car body or pressed on the suspension arms.

Through the suspension displacement, caused by the external forces, the bushings undergo elastic deformations, in fact the joint having six degrees of freedom. The theoretical study of the guiding linkages has in fact a symbolical representation of the bushings by spherical joints. The deformation of the bushings is neglected for the rigid model to be created.

The rigid model is a simple model, with few degrees of mobility (M=1 or M=2), so the study can be made by classical/traditional methods [1]-[5].

By taking into account the simplified representation of the bushings (replacing them with spherical joints), the structural systematization of the guiding linkages of the rear axle was developed in [3].

The guidance of the axle is performed by the guidance of a number of its points around specific surfaces and curves (Fig. 1). The guidance on a sphere (S) is obtained by a binary link with spherical joints in both ends, interposed between the axle and the car body. The guidance of an axle point in a circle (C) is achieved from triangular links with two joints to the car body the guidance on coupler curve (CC) is performed by a spherical joint between axle and coupler (c); in this case Watt configuration is usually used, but Roberts, Chebyshev or Evans straight - line linkages can also be used [6]–[8]. There can be obtained various guiding linkages with M=1 and M=2 degrees of mobility by joining in parallel the types of guidance shown in Fig. 1.

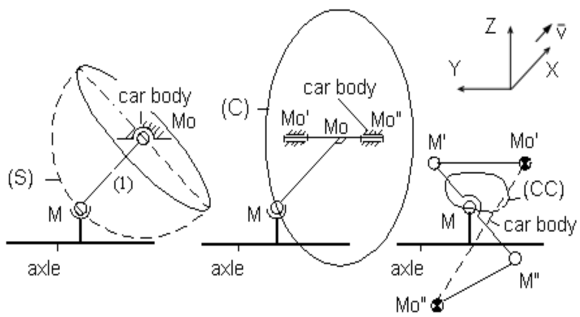

Fig. 1. The basic types of guidance for the rear axle of the vehicles [3].

The growing demand for more comfortable and safety vehicles imposes a new way for the dynamic analysis of the guiding axle linkages, with elaboration of models that are closer to the real mechanisms [9]–[12]. The degree of freedom of the guiding system is increasing and its difficulty to analyze such models with classical methods.

For the suspension systems that have many degrees of freedom, it is necessary to use mechanical systems analysis software (such as MSC ADAMS) that formulate and solve the motion equations automatically [13], [14].

The main goal of this paper is to evaluate the effect of the bushings' flexibility (deformability) in the static analysis of the rear axle guiding linkages. The idea is to comparatively analyze the static behavior of the rigid model (with spherical joints) relative to the real elastic model (with compliant joints), with the aim to establish if the rigid model assumption is useful for the static analysis.

The comparative analysis between the compliant and rigid models is applied considering the general cases of guidance of the rear axle, with mono-mobile (by five points - 5S) and bi-mobile (by four points - 2S1C) mechanisms; these are some of the most used types of mechanisms for guiding the rear axle of the motor vehicles (mainly for the commercial and off-road vehicles).

II. Models in Study

The static model of the suspension system is a constrained, multi-body spatial mechanical system, in which the bodies (car body, rear axle, guiding arms, rims) are connected through geometric constraints, compliant joints, and force elements (springs, dampers, bumpers, tires). In this paper, different models for rear axle suspension are comparatively analyzed, by considering the linear & angular elastic restricted deformations in bushings.

The aim of this study consists in establishing of simply models which are closer to the general compliant model. With this end in view, the static model of the suspension system was developed, at which the car body is fixed on ground (the base of the mechanism).

The model takes into consideration the elastic elements of the system (springs, rubber bumpers limiting the run, tires), the external loading being made by a vertical force applied on the left wheel, in stationary regime (Fig. 2), $F_l^z \in [0 \ldots 800]$ daN. This is similar with the static experimental test using a vehicle simulator, at which the right actuator is fixed and the loading is made by the left actuator.

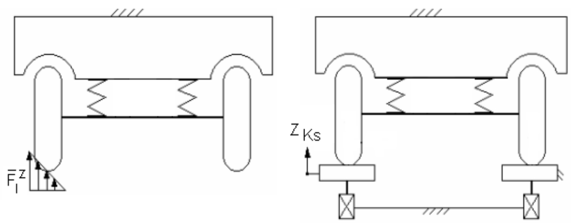

Fig. 2. The schematic representation of the static model (analysis).

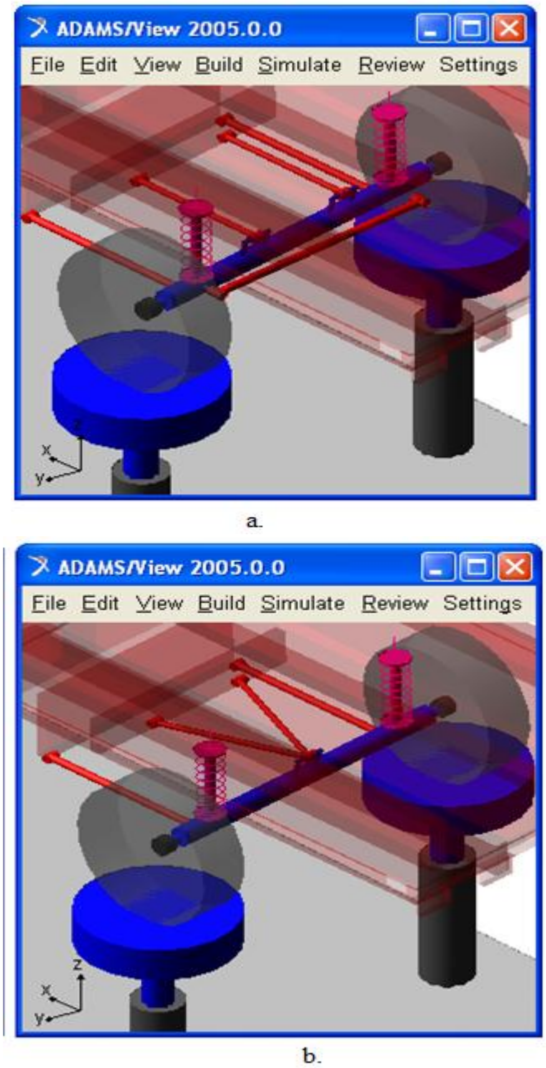

Fig. 3. The MBS models of the guiding linkages in study: a) 5S (M=1), b) 2S1C (M=2).

The guiding linkages that have been analyzed correspond to the rear axle of some domestic vehicles: ARO Spartana (5S - Fig. 3, a), and DACIA 1300 (2S1C - Fig. 3, b). The mechanisms have been modeled in the global reference frame XYZ, which is fixed in car body: X-axis is towards the front of the car and lies in the longitudinal plane of symmetry, Y-axis is towards the driver's left, and Z-axis is directed upward. In both mechanisms, the wheels are mounted at either end of a rigid beam so the movement of one wheel is transmitted to the opposite wheel causing them to steer and camber together. Bushing elements (in the compliant model), or spherical joints (in the rigid model), connect the guiding links to the solid axle and to the car body. Revolute joints connect the axle spindle to the tires (wheels).

The translational springs & dampers are concentrically disposed between car body and axle, but in the static analysis the damping properties are not taken into consideration (because the damping forces depend on velocities). However, there are considered the mass effects of the dampers, and for this reason the lower and upper struts of the dampers were modeled as rigid parts, which are connected through cylindrical joints; the connections to the adjacent parts (car body & axle) are made through spherical joints. The rear axle suspension also contains bumpers and rebound elements. These are non-stationary elastic elements which limit the suspension displacement (compression - expansion), being disposed inside the dampers.

The connections between the wheels (tires) and the sustaining plates were assured using contact forces. These allow modeling how adjacent bodies interact with one another when they collide during the simulation. ADAMS models the contact as a unilateral constraint, that is, as a force that has zero value when no penetration exists between the specified geometries, and a force that has a positive value when penetration exists between two geometries. The specific ADAMS/Solver module has a geometry engine (RAPID) that is responsible for detecting contact between geometries, locating the points of contact, and calculating the common normal at the contact points [15]. Once the contact kinematics is known, contact forces, which are a function of the contact kinematics, are applied to the intersecting bodies.

The guiding function of the mechanism is defined by the motion of the rear axle relative to the car body, being modeled by the following parameters: the displacements of the axle's centre along the longitudinal, transversal and vertical axes, the roll rotation of the axle, the rotation of the axle around its own axis, and the yaw rotation of the axle. In paper, the difference between the compliant model (with bushings) and the rigid model (bushings modeled as spherical joints) is analyzed considering the main motions of the axle, namely the roll angle (η_x), and the vertical displacement of the axle's centre (Z_P); the influence on the other parameters is very small (negligible). In these terms, the objective of the study is to establish if the rigid model assumption is useful (or not) in the static analysis of the axle guiding linkages.

III. Results and Conclusions

The previously presented models have been coded in ADAMS format through the pre-processing interface ADAMS/View. Analyzing the compliant & rigid models for the representative guiding mechanisms in study (5S and 2S1C), we obtained the time-history variations for the interest motion parameters (the roll angle of the axle, and the vertical displacement of the axle's centre), which are shown in the diagrams from Fig. 4.

The following conclusions can be formulated: in the case of the linkages with M=2 degrees of mobility (2S1C, in this case), the rigid model assumption can be accepted, because the behavior of the rigid model is closed-by the compliant model; for the guiding linkages with M=1 (5S), there are significant differences between the rigid model and the compliant model, so that the rigid model assumption is no useful for the static analysis.

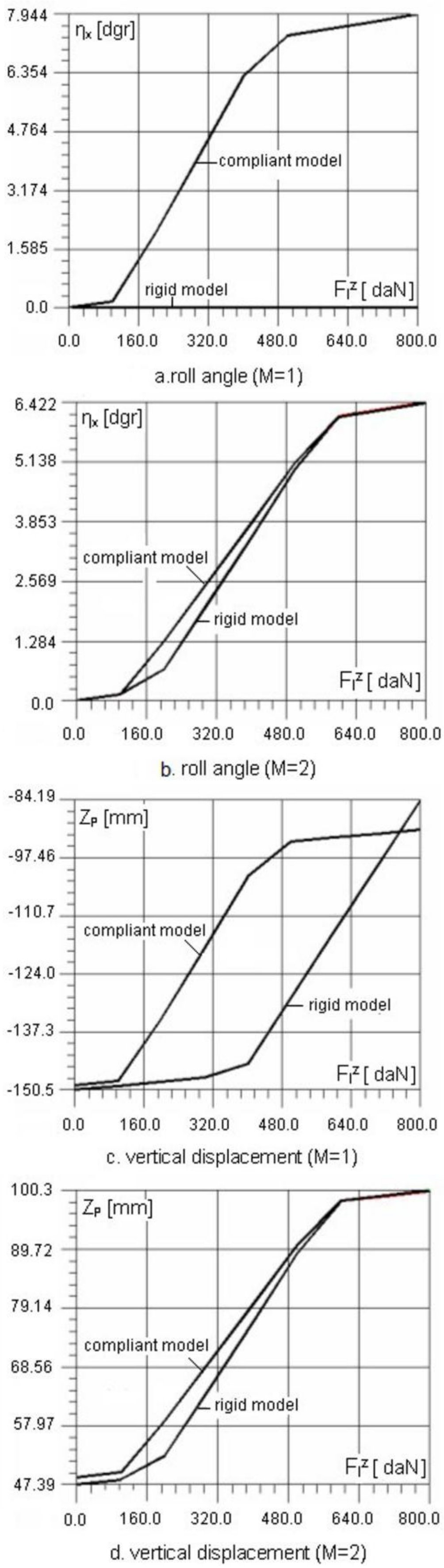

Fig. 4. The results of the static analysis for the guiding linkages with M=1 and M=2.

These results were also verified and validated for other types of axle guiding linkages with M=1 and M=2 degrees of mobility.

Under these circumstances, for the guiding linkages with M=1, there is necessary to develop new models for bushings, closed-by the real compliant joints, by taking into account the elastic restricted linear deformations. Therefore, the study is developed having in view to identify the influence of each linear deformation on the guiding function of these mechanisms. With this end in view, the bushings have been modeled as spherical - translation composite joints, with 4 degrees of freedom (DOF), as follows: X-model and Z-model, on which the radial transversal or vertical deformation is allowed in the limits of the radial rigidity (DOF: θ_x, θ_y, θ_z, Δ_x or Δ_z); Y-model, on which the axial deformation is allowed in the limits of axial rigidity of the bushings (DOF: θ_x, θ_y, θ_z, Δ_y).

The comparative analysis for these models has been made by considering the above-described static test (see Fig. 3, a). The results are presented in the diagrams shown in Fig. 5. As can be see, the X-model is closed-by the compliant model, and the Y-model is closed-by the rigid model.

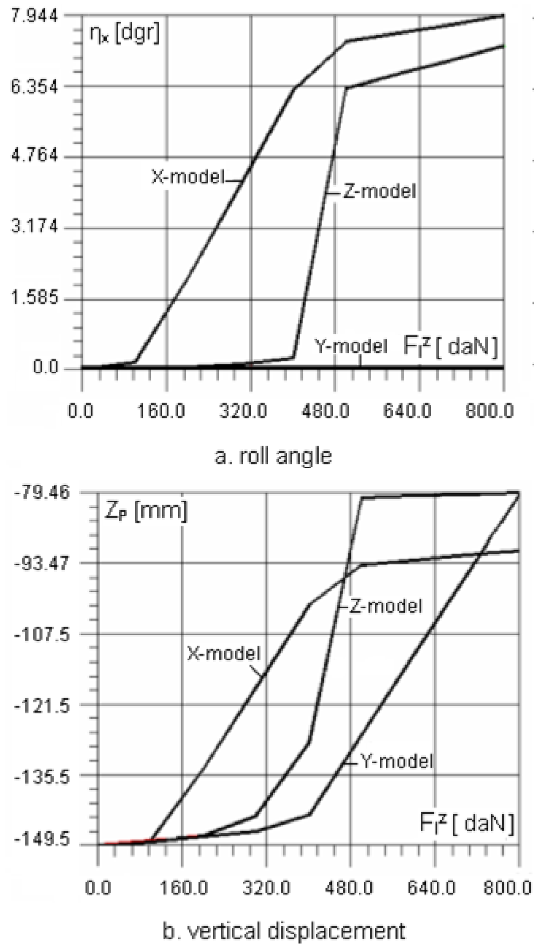

Fig. 5. The results of the static analysis for the guiding linkages with 4-DOF joint models.

Therefore, the simplest model for the compliant joints used to the guiding linkages of the rear axle is the spherical - translation composite joint, which allows three angular deformations (θ_x, θ_y, θ_z) and one radial deformation (Δ_x) - in the case of the guiding mechanisms with M=1 degree of mobility, and the spherical joint - for the mechanisms with M=2 degrees of mobility, respectively.

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