Influence of the Deformations in Bushings on the Dynamic Behaviour of the Vehicles' Rear Axle Guidance Systems

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***Abstract*—The work investigates the influence of the deformations in bushings on the dynamic behaviour of the rear axle guidance systems of vehicles, actually continuing a previous study in which the problem was approached from a static point of view. In the comparative analysis, there are considered two models for the joints (bushings) through which the bars of the guidance mechanism are connected to the adjacent parts (chassis and axle, respectively), namely spherical joints, which consider only the rotational movements, and flexible/compliant joints, which consider both linear and angular mobilities. The study, which is developed for the two structural types of guidance mechanisms (depending on their number of degrees of mobility), was conducted using the virtual prototyping package ADAMS (Automated Dynamic Analysis of Mechanical Systems) of MSC Software.**

***Index Terms*—motor vehicles, rear axle, guidance mechanism, dynamic model**

I. Introduction

The suspension system of the vehicles' rear axle consists of a set of parts that are joined by mechanical connections, elastic & damping elements; on them acts a complex system of external forces, depending on the loading and running regime of the vehicle, as well as internal forces generated by the elastic and damping components.

The dynamic model of the axle suspension system is obtained by completing the kinematic model, described / approached in previous works of the author [1–4], with the mass & inertial properties of the parts, the positioning parameters of the elastic and damping components (springs, buffers for limiting the suspension stroke, bushings, tires, shock absorbers), the elastic (force vs. deformation) and damping (force vs. speed) characteristics, and the external forces acting on the vehicle in the specific dynamic running regime. The modeling of the elastic and damping elements was depicted in [5], within an analytical method for establishing the balance/equilibrium configuration.

The structural systematization of the rear axle guidance mechanisms was presented in [1], considering the hypothesis that the guidance arms' joints to the adjacent parts (chassis and rear axle), which in reality are compliant joints (bushings) with 6 elastic restricted degrees of freedom (Fig. 1a), are defined by spherical/ball joints with 3 degrees of freedom (Fig. 1b), thus neglecting the linear deformations in bushings. In this way, two types/groups of rear axle guidance mechanisms have been systematized, namely mechanisms with one or two degrees of mobility.

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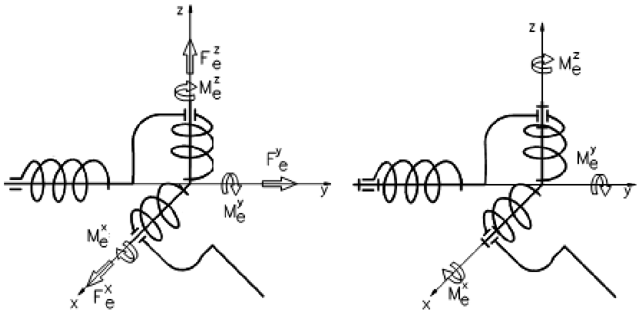

Fig. 1. The compliant (a) and spherical (b) joint models.

With the view to establish the viability of the spherical joint model, the influences that the deformations that appear in bushings have on the behaviour of the suspension system need to be evaluated. This problem can be studied both statically (when the chassis is fixed) and dynamically (vehicle in motion) [6–10].

The results regarding the influence of deformations in bushings on the static behaviour of the rear axle guidance systems were presented in [11]. The work actually aimed at the influence of deformations in bushings on the spatial movement of the rear axle. The aim was to determine the structural group of mechanisms in which the hypothesis of the spherical joint model is usefulness, referring to the accuracy of the results compared to those provided by the real compliant model. The static study was subsequently extended in [12].

In the case of dynamic regimes (when the vehicle is moving), such a study should be focused on the way in which the movement from the raceway to the car body is transmitted, focusing primarily on the dynamic behaviour (i.e., oscillations) of the car body. The study in this work is based on the simulation of MBS (Multi-Body System) models of the approached suspension systems, which were developed using the virtual prototyping package ADAMS. Important advantages are obtained by using such a software solution, as stated in [13–16].

II. Models in Study

In this work, the comparison (in terms of dynamic behaviour/response) between the suspension systems with compliant and respectively spherical joints was carried out by considering representative variants for the two basic structural types of axle guidance mechanisms, depending on their number of mobilities (M), as follows (for details on coding, see [1]): guidance mechanism of type 5S - for M=1 (Fig. 2a); guiding mechanism of type 2S1C - for M=2 (Fig. 2b).

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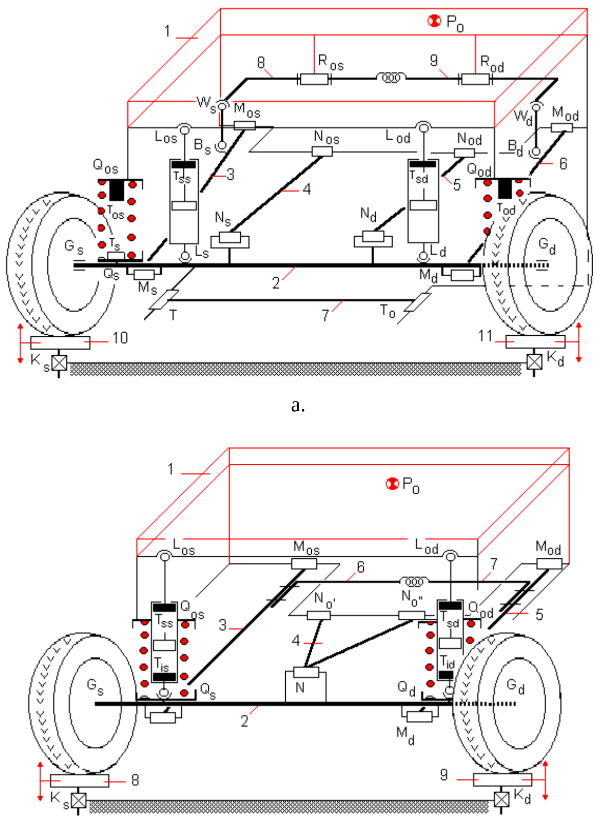


a.

b.

Fig. 2. The rear axle suspension systems based on 5S (a) and 2S1C (b) guidance mechanisms.

The 5S mechanism contains five binary arms, of which four are arranged longitudinally (3, 4, 5, 6) and one transversely (so called Panhard bar-7), each with a single connection to adjacent bodies (car body-1, and axle-2), while the 2S1C mechanism has three longitudinal arms, the central one (4) being double-articulated to the car body (in $N_{0'}$ and $N_{0''}$). The suspension mechanism also includes elastic and damping components (springs, dampers, bumpers and rebound elements, anti-roll bar). The numerical values and the disposing of the suspension elements correspond to a vehicle of type ARO—n the case of the 5S guidance mechanism, respectively DACIA—for the 2S1C guidance mechanism.

The dynamic models were tested in passing over bumps regime. In this regard, two additional parts (actuators) were used to model the tire contact patches (marked by 10–11 in Fig. 2a, and respectively 8–9 in Fig. 2b). The tread bumps were transposed in the virtual models developed in ADAMS by motion generators that control the vertical travel of the two actuators, as follows: the left wheel crosses an obstacle with the amplitude of 90 mm, the vertical displacement of the actuator being modeled by a Cubic Spline function; the right wheel is not excited, as if moving on a smooth road (so, the right actuator is fixed).

For ensuring the car body equilibrium, the lack of front axle is substituted by a fictitious ball joint between chassis and ground (Fig. 3), which is placed in the median-longitudinal plane, on the front wheels axis (in P_0). In this way, there are possible the rotational oscillations of the car body, namely roll (θ_x), pitch (θ_y) and yaw (θ_z). Previous research has shown that this half-car model ensures results very close to those provided by the full-vehicle model [17].

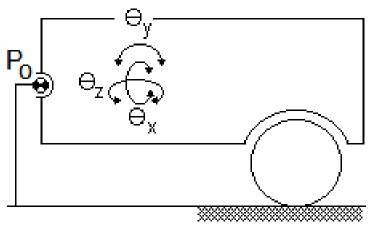
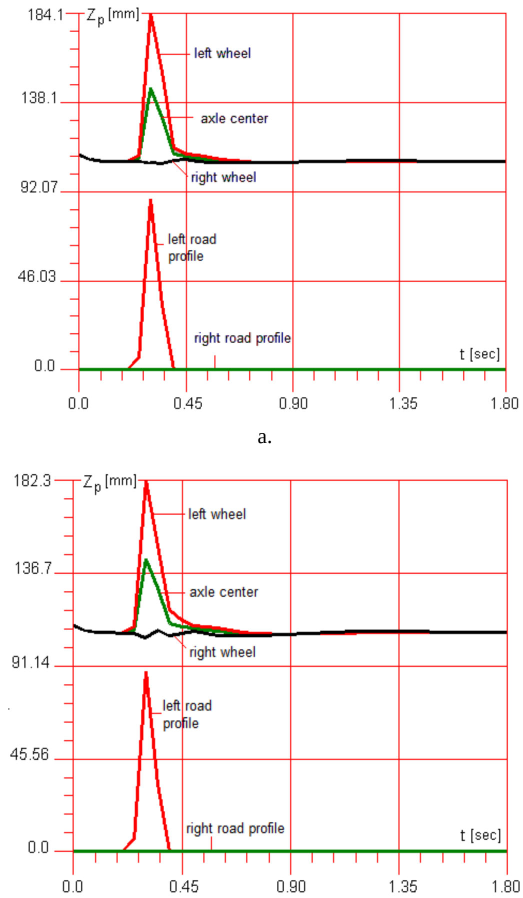


Fig. 3. Half-vehicle model with ball joint.

From a dynamic point of view, the parameters that best reflect the effect of deformations in bushings correspond to the roll and vertical oscillations, for both car body and axle. Obviously, the other parameters that define the dynamic response are also influenced, but their variation is still insignificant compared to that of the two mentioned parameters.

III. Results And Concluding Remarks

As mentioned before, comparison between the dynamic models in the study was achieved by using certain modules in the commercial programme ADAMS, namely ADAMS/View—for preprocessing (modeling), and ADAMS/Solver—for processing (analysis). The results of this study are shown in Figs. 4–6 (for the suspension system based on 2S1C guidance mechanism), and Figs. 7–9 (for the suspension system based on 5S guidance mechanism).



a.

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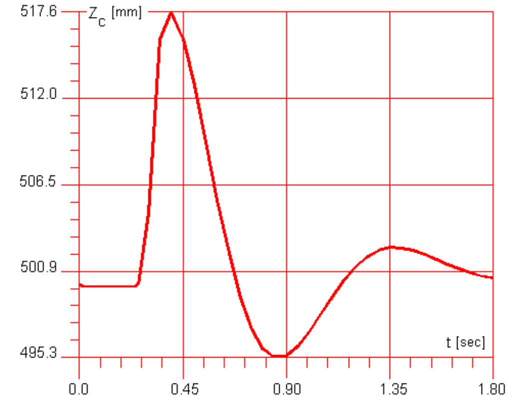
Fig. 4. Vertical displacements on the axle level for the 2S1C mechanism: spherical joint model (a), compliant joint model (b).



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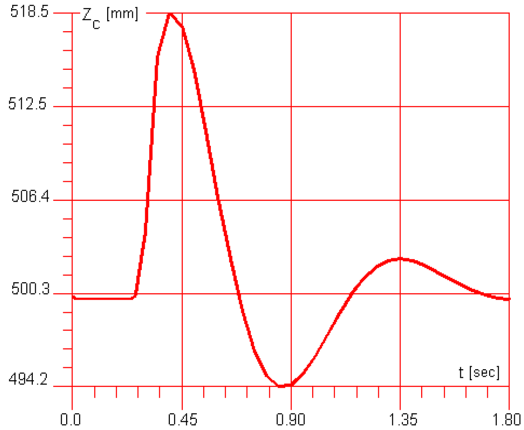

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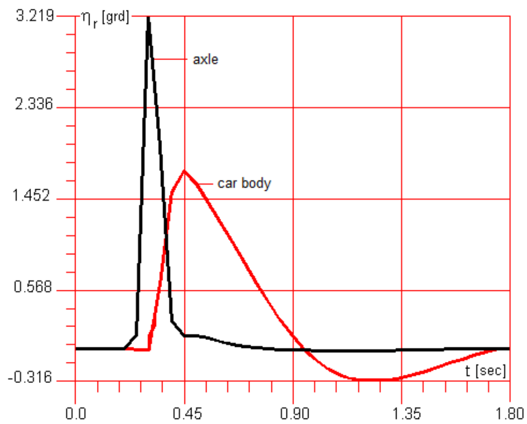
Fig. 5. Vertical displacements of the car body for the 2S1C mechanism: spherical joint model (a), compliant joint model (b).



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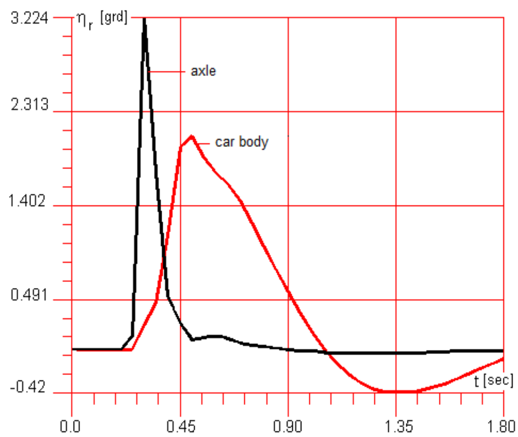

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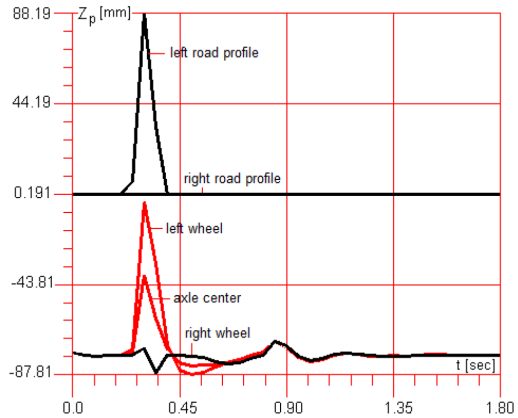
Fig. 6. Roll oscilattions of the car body and axle for the 2S1C mechanism: spherical joint model (a), compliant joint model (b).



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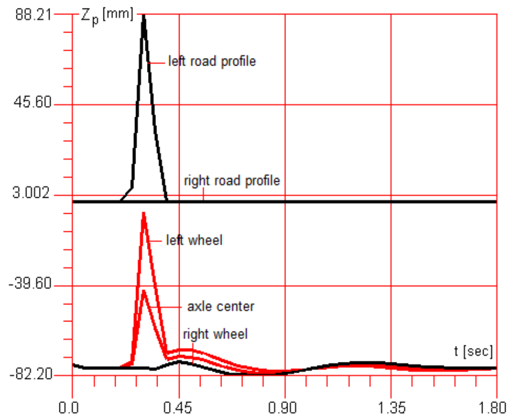
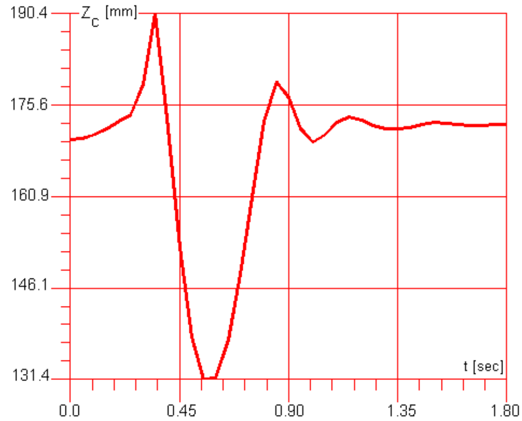


b.

Fig. 7. Vertical displacements on the axle level for the 5S mechanism: spherical joint model (a), compliant joint model (b).



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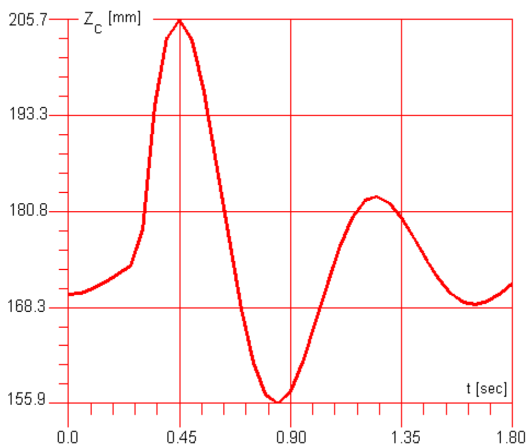

b.

Fig. 8. Vertical displacements of the car body for the 5S mechanism: spherical joint model (a), compliant joint model (b).

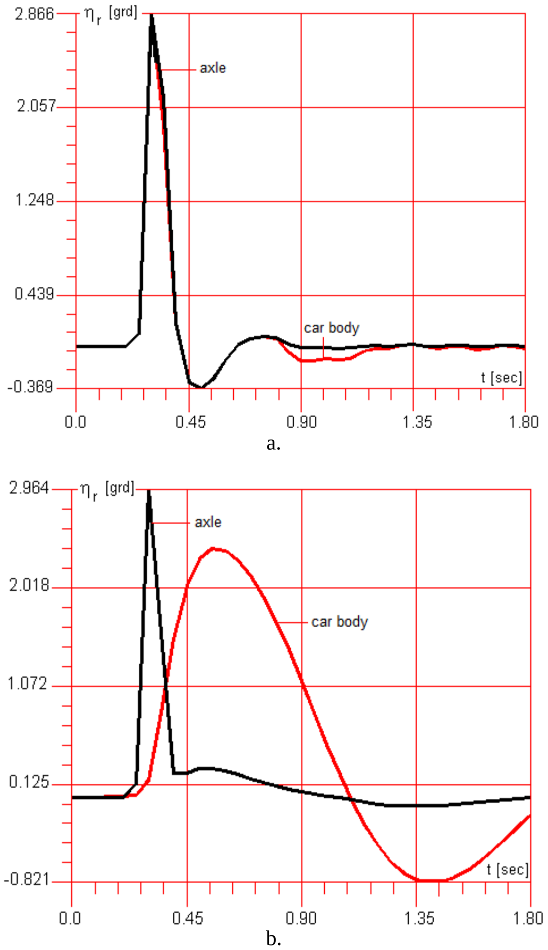

Fig. 9. Roll oscilattions of the car body and axle for the 5S mechanism: spherical joint model (a), compliant joint model (b).

The diagrams presented in these figures reveal the following:

- for the both axle guidance mechanisms (2S1C and 5S), the movements of the rear axle are approximately the same in the case of the spherical and compliant joint models, mainly because the axle has to follow (by the left-right wheels) the road profile;
- the dynamic response for the spherical joint model in the case of the 2S1C guidance mechanism is quite close to that corresponding to the compliant model (connections made by bushings);
- for the suspension system based on 5S guidance mechanism, the spherical joint model generates substantially different results from those of the compliant joint model in terms of car body oscillations; because the axle must follow the running path, for reasons related to the guidance conditions of the axle, the rolling movement of the axle is accompanied by the simultaneous tilting of the car body (which obviously does not happen in the real case).

The significant differences in terms of dynamic behaviour (response) between the spherical and compliant models in the case of the vehicle suspension system based on 5S guidance axle mechanism are also highlighted by the graphical animation frames depicted in Fig. 10, where frame “1” corresponds to the simulation time t=0.3, frame “2” – t=0.6, frame “3” – t=0.9 (the unit of measurement for time is the second).

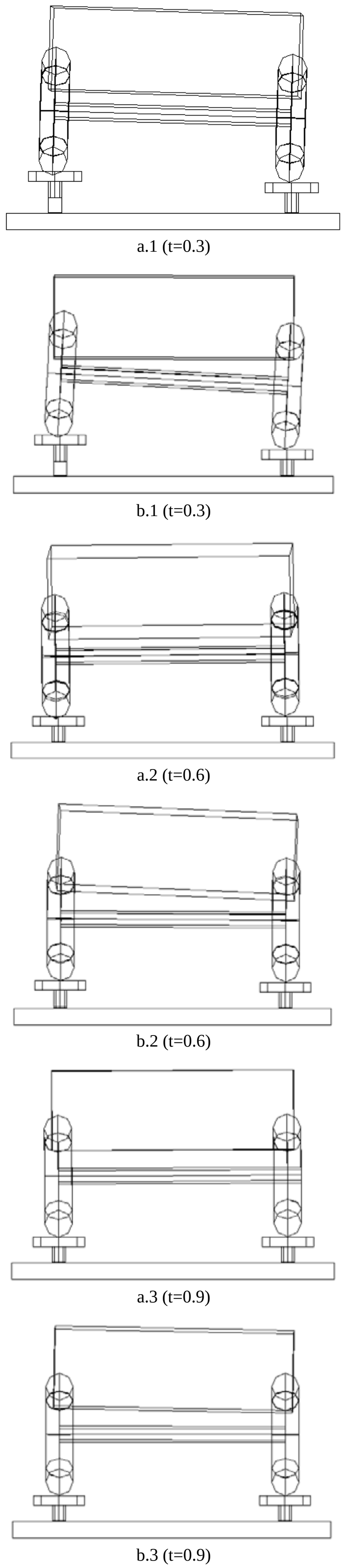

Fig. 10. Graphical simulation frame for the suspension system based on 5S guidance mechanism: spherical joint model (a), compliant joint model (b).

In conclusion, the bi-mobile axle guidance mechanisms can be analyzed in the hypothesis of the spherical joint model not only from a static point of view, as revealed in [11, 12], but also dynamic, thus reducing the complexity of the theoretical / virtual model.

On the other hand, in the case of the axle guidance mechanisms with a single mobility, the spherical joint model, which neglects the linear deformations, is inefficient both statically and dynamically, which involves the use of joint models closer to the real compliant joint model (i.e., bushing/flexiblock), which is reflected in a higher complexity of the model.

Conflict of Interest

The author declares no conflict of interest.

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