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A study on the effect of the deformations in flexiblocks on the behavior of the vehicle axle suspension mechanisms

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Abstract. This work deals with a study on the effect of the deformations in flexiblocks (bushings) on the behavior of the vehicle axle suspension mechanisms. The mechanism in study is a representative one for the structural group/class of mono-mobile axle suspension systems, namely the guiding mechanism by five points - on five spheres (so called 5SS). In a previous work, it was established that the rigid joint model for this class of mechanisms does not provide results close to the real flexible bushing model, reason for which the research in this paper is directed towards the identification of a theoretical model of joint which, at a lower complexity than that of the real model, would still provide viable results, in terms of axle guidance accuracy in the spatial movement relative to car body. In this regard, static and kinematic models were developed and analyzed by using the MBS (Multi-Body Systems) software solution ADAMS.

1. Introduction

The suspension mechanisms of vehicles' rear (beam) axles perform two functions, namely the function of guiding the beam axle in movement relative to car body, respectively the function of transmitting the contact forces from wheels. Regarding the guiding function, this is defined by the spatial movement (position and orientation) of the axle, which is established by the positional analysis of the guiding mechanism. The guidance function is studied on models in which the car body is considered fixed (namely, kinematic and static models). In the case of the dynamic model, where the car body is a mobile part, the axle is forced, by wheels, to follow the road profile (more or less accurately, depending on the elasticity of the tires).

Therefore, the analysis of the guidance function can be performed on the kinematic model, considering the loading of the mechanism through vertical positions imposed on the wheels, respectively the static model, where the external loading is performed by forces applied to the wheels. Obviously, the determination of the guidance function on the static model is closer to reality, because the elastic elements of the suspension are also taken into account.

The (quasi)static analysis of the axle guiding mechanisms can be performed on the basis of two models, in correlation with the modelling of the connections between the guiding bars and the adjacent parts (car body and axle), which are actually made by flexiblocks/bushings (compliant joints that support linear and angular deformations), as follows: rigid models, in which the bushings are modelled by spherical couplings/joints, with 3 degrees of freedom (DOF) corresponding to the rotational movements (these models are also the basis of the structural synthesis and kinematic study of the axle guiding mechanisms [1]); flexible/compliant models, with 6 degrees of freedom restricted elastically, which considers both linear and angular movements (deformations).



Opting for one or the other model is, first of all, a choice dictated by the available computational tool. If the rigid models, due to the low degree of mobility they have ($DOM = 1$ or $DOM = 2$), are suitable for analysis by specialized methods and in-house programs, the elastic models, with a large number of degrees of mobility, require the use of MBS (Multi-Body Systems) commercial software solutions, which are actually used in a large variety of applications [2-6]. Approaching the compliant bushing model through classical formalisms, in addition to being extremely difficult, involves the risk of obtaining significant computation errors, a consequence of the particularly vast mathematical apparatus that should be managed. For the positional analysis of the axle guiding mechanisms, there is frequently considered the simplifying assumption that the rigid models approximate quite well the behaviour of the real models with compliant bushings. Obviously, the following problem/question can be raised: what is the deviation/error generated by the symbolic representation of bushing by spherical coupling regarding the guiding function of the mechanism? It is interesting, in fact, for which category of axle guiding mechanisms the rigid model hypothesis can be accepted, regarding the accuracy of the results provided for the axle movement, compared to the flexible model.

In the literature such a problem is addressed mainly for front wheel guiding mechanisms (four-bar, McPherson and multi-link configurations) [7-13]. The conclusions of these works converge on the idea that, although there are some differences between the behaviour of rigid and flexible joint models in terms of guiding accuracy, the rigid model is a viable alternative for the positional analysis of the wheel guiding mechanisms. These approaches are especially kinematic, as it is not possible to make a quantitative assessment of the dimensional deviations in bushing (i.e. the deformations as a function of forces), much less a correlation between the deformations for all bushings in the guiding mechanism.

In a previous work by the author [14], a comparative analysis between rigid and flexible joint models for the two main categories of axle guiding mechanisms (in terms of the number of degrees of mobility, $DOM = 1$ and $DOM = 2$) was carried out. A similar study was performed in [15], by considering other structural variants of axle guiding mechanisms and respectively numerical values of the specific geometric parameters. The conclusions resulting from these papers can be summarized as follows: the hypothesis of the rigid coupling model is valid only in the case of bi-mobile ($DOM = 2$) axle guidance mechanisms, while in the case of mono-mobile ($DOM = 1$) mechanisms, it is necessary to consider models of couplings/joints closer to reality (i.e. compliant bushings), which must allow linear deformations.

Starting from the previously mentioned research, the present work deals with a more detailed study on the influence of the joints' deformations on the guidance function of the mono-mobile axle suspension mechanisms (for which the rigid joint model hypothesis is invalid), in order to identify the simplest models that ensure an appropriate behavior, close to that of the real model. The study is conducted by developing and testing MBS models made by using the virtual prototyping environment ADAMS of MSC.Software.

2. The MBS model of the suspension system

To study the influence of elasticities in bushings on the guiding function of the axle suspension mechanisms, the static model of the mechanism was initially developed, considering that the car body is fixed and the external loading of the guiding mechanism is realized by forces applied to the wheels. The suspension system in study is based on an axle guiding mechanism by five points - on five spheres (5SS), whose equivalent structural model has a single degree of mobility, corresponding to the vertical movement of one of the wheels (left or right).

The static model of the suspension system based on 5SS axle guiding mechanism, which is shown in Figure 1, contains the bodies/parts in the suspension system (axle & wheels, guiding links/bars, car body), the connections between bodies (which in the real case are made by bushings), the spring & damper assemblies (which are arranged between the axle and the car body), the compression & extension bumper stops (which are arranged inside the shock absorbers / dampers, thus limiting the relative movement between their pistons and cylinders).

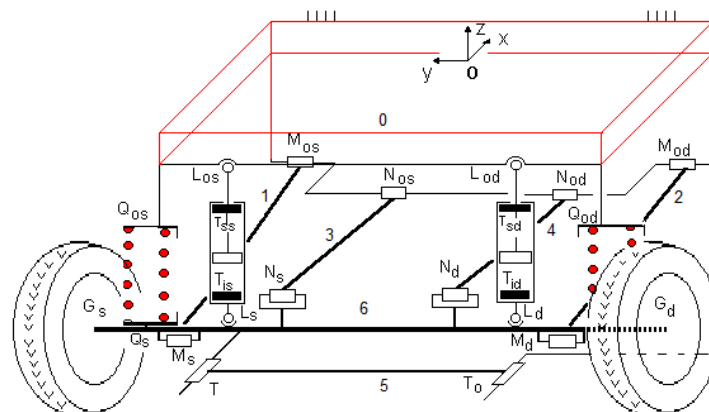


Figure 1. The static model of the 5SS suspension system.

For this type of axle suspension systems, there were modeled and analyzed rigid (where the connections of the guiding bars to axle and car body are made by spherical couplings/joints) and flexible (couplings by bushings) models. By taking into account the bushings' elasticity, all the parameters that describe the guiding function of the mechanism (i.e. the spatial movement of the axle) will obviously be influenced. The guiding function of the mechanism is reported/defined by the roll angle and the vertical coordinate of the axle's center, because these are the parameters that actually describe the global character of the spatial movement of the axle relative to the car body.

3. Results and conclusions

The comparative analysis of the rigid and flexible models was carried out for several functional situations determined by the nature and values of the wheel contact forces. In this work, the test model considered corresponds to the situation where the vehicle is suspended, with the car body locked, and it is operated on the left wheel by a variable vertical force (F_z), in the range of values $F_z \in [0, 800]$ daN. The results of these analyzes led to conclusions similar to those of previous researches [14, 15] confirming the invalidity of the rigid joint model in the case of the mono-mobile suspension system.

Further, it was started from the premise that it might be possible that for certain types of bushings, where due to high stiffnesses there are practically no linear deformations, the behavior of the flexible model is close to that of the rigid model. From the point of view of the linear (radial and axial) deformations that occur in bushings, the flexible model for the 5SS guiding mechanism led to the results shown in Figure 1, for the connections on axle of the lower longitudinal bars (1 - left, 2 - right), the upper longitudinal bars (3 - left, 4 - right), and the transversal bar (5). Similar deformations were obtained for the bushings through which the guiding bars are connected to car body. According to these diagrams, the linear deformations in bushings are very small, of the order of tenths-hundredths of a millimeter. So, there are enough small deformations in bushings for the law of motion through the flexible model to be very different from that of the rigid model. The question then arises: what should a bushing look like from a geometric point of view in which not even such small deformations appear?

According to the relations in [16], the linear rigidities in bushings are mainly influenced by the thickness of the rubber intermediate layer. High rigidities, which determine even the proximity of the condition of linear non-deformability of the elastic element (a necessary condition for the validation of the rigid model), involve an extremely small thickness of the rubber between the outer and inner metallic rings of the bushing. However, such a constructive solution would have effects on the necessary angular mobility, on the sound and anti-vibration insulation capacity of the bushing. Moreover, the symbolic representation bushing \rightarrow spherical coupling, which is the base of the structural synthesis [1], would no longer be valid either, because in fact the spherical rotations could no longer occur. The analysis of a large number of constructive solutions showed that no constructive variant of bushing, at least the known ones, does not provide the necessary conditions for the validation of the rigid model for the mono-mobile axle guiding mechanisms.

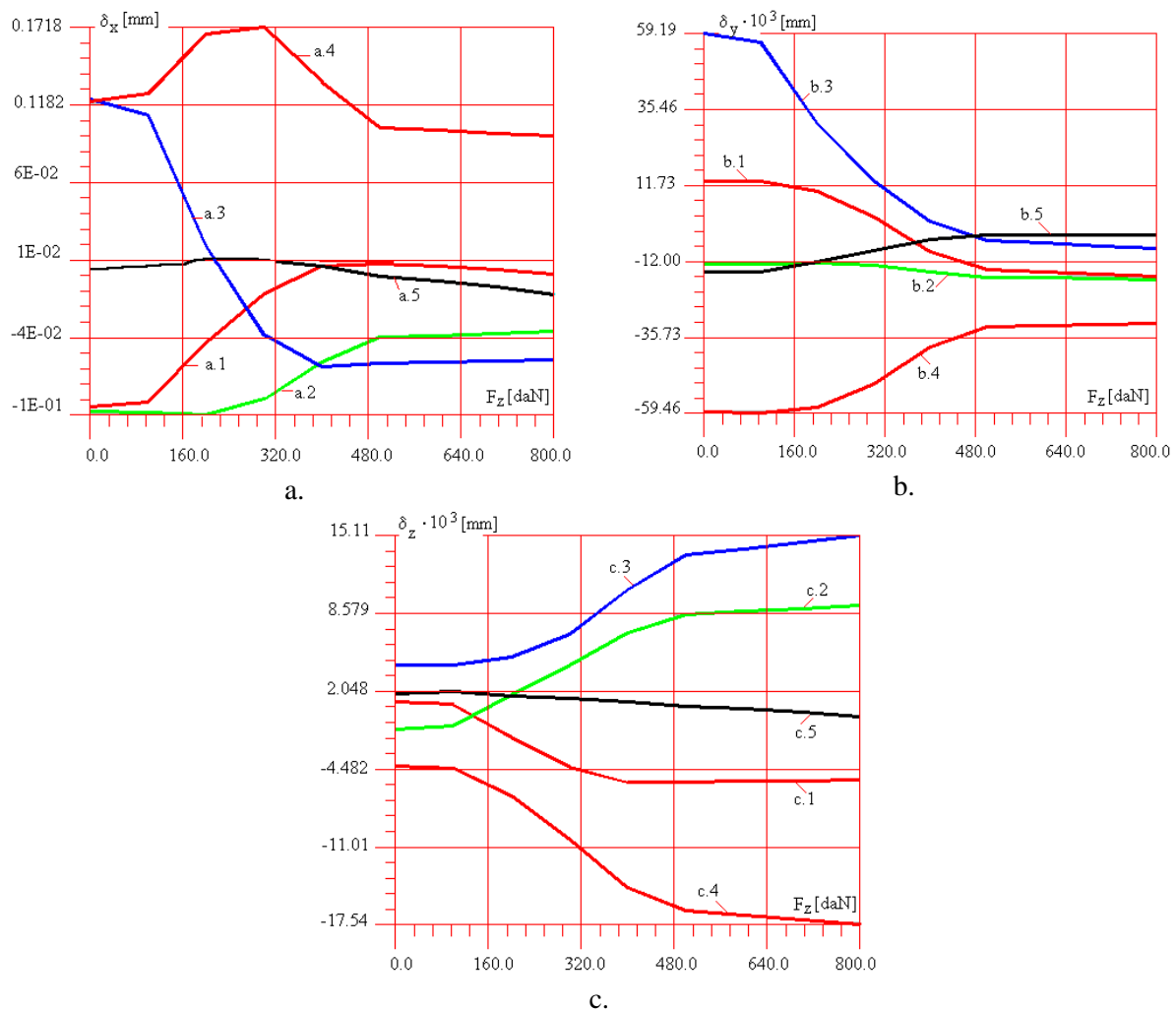


Figure 2. The radial and axial deformations in bushings for the 5SS axle guiding mechanism.

On the other hand, the analysis of the guidance function of the axle guiding mechanisms can also be performed on the kinematic model. For this, the elastic and damping elements (springs, dampers, bump stops) are removed from the suspension system, and the input (actuating) is made through vertical positions imposed on the left wheel ($\Delta Z_{Gs} \in [-80, 80]$ mm, from the static/rest position when $Z_{Gs} = -77$ mm). Because the kinematic model does not contain the elastic suspension elements, which would generate internal reaction forces, the linear deformations in bushings are much smaller than in the static model. Even under these conditions, according to the diagrams in Figure 2, the rigid model for the guiding mechanisms with $DOM = 1$ behaves differently from the flexible model, referring to the law of motion by the guiding mechanism, which strengthens the conclusion regarding the invalidation of the rigid joint model for this structural group of mechanisms.

Since in bushings there are, theoretically, linear deformations in all directions (axial and radial), the influence of each linear elasticity characteristic on the guiding function of the axle suspension mechanism will be further identified. In this regard, the bushings were modeled by connections with 4 degrees of freedom (DOF), considering in addition to the spherical rotations one of the linear deformations (along X, Y, Z, by case), the 4-DOF coupling models being defined by compound sphere-translation joints. Such an approach allows the identification of the simplest model for bushing, which is able to ensure a behavior close to that of the real 6-DOF bushing. The results obtained by analyzing the 4-DOF joint models for the parameters of interest that define the spatial position of the axle are shown in Figures 3 and 4 (a - static analysis, b - kinematic analysis).

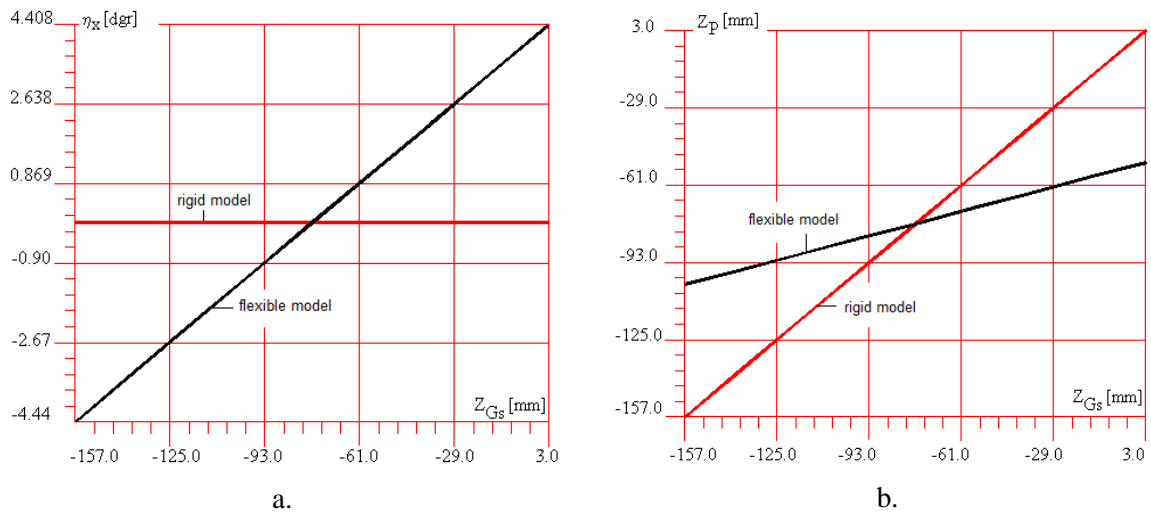


Figure 3. The results of the comparative analysis for the kinematic models.

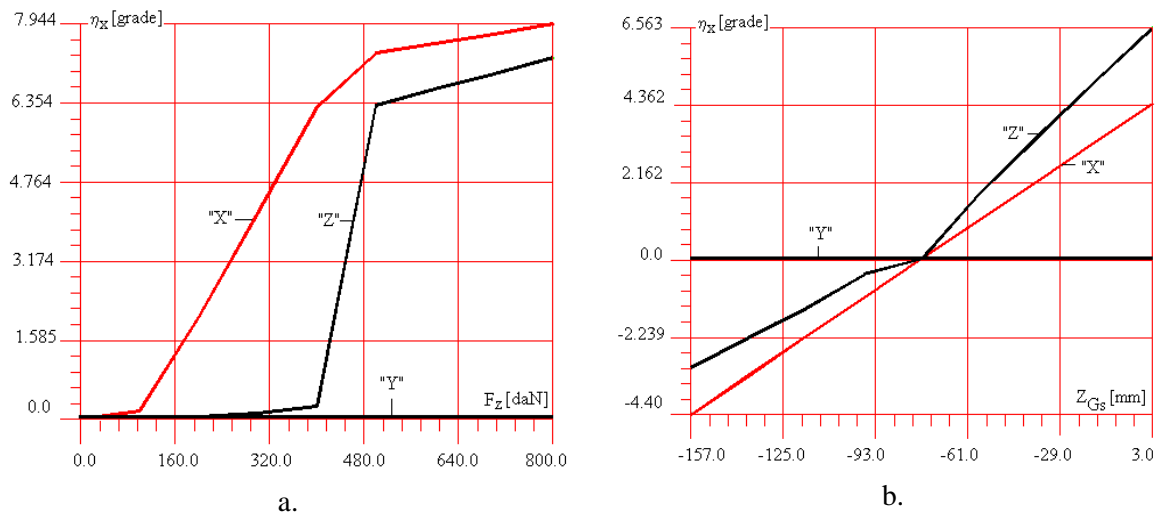


Figure 4. The roll angle of the axle for the 4-DOF joint models.

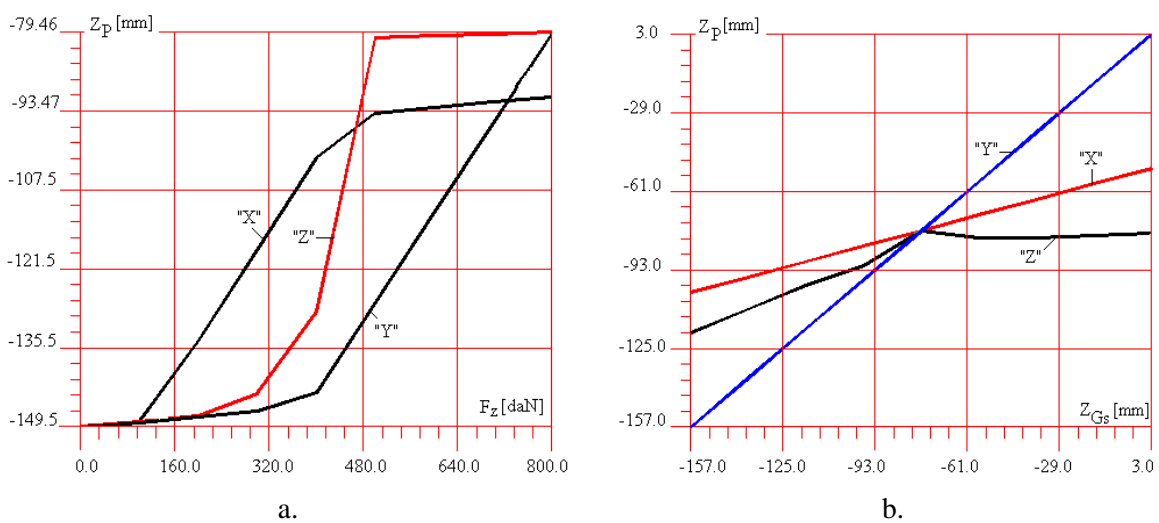


Figure 5. The vertical displacement of the axle's centre for the 4-DOF joint models.

According to these diagrams, the 4-DOF joint model "X", which allows radial linear deformation along X, leads to results close to the real compliant model (with 6-DOF bushings), while the 4-DOF joint "Y", which allows axial linear deformation along Y, is very close to the rigid model (with 3-DOF spherical joints). Therefore, the simplest viable model for rear axle bushings is the composed sphere-translation joint on the longitudinal axis, with 4 elastically restricted degrees of freedom. Consequently, the main reaction forces in bushings are the longitudinal ones, while and lateral reaction forces (along the bushing's axis) are practically insignificant. This information is also important for the proper sizing of the bushings in the 5SS axle guiding mechanism.

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