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DYNAMIC ANALYSIS OF A MULTI-LINK SUSPENSION MECHANISM WITH COMPLIANT JOINTS

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Abstract: *The increasingly growing demand for more comfortable cars imposes a new way for dynamic analysis of the axle guiding linkages, with elaboration of models that are closer to the real mechanisms on the car. In this paper, the influence of the compliant joints on the dynamic behavior of the suspension system is approached, considering the axle guiding linkage used for an off-road vehicle. A half-car model is taken into consideration, which contains the suspension system of the rear axle. In the lack of the front suspension, modeling a fictive spherical joint between car body and ground ensures the equilibrium. The dynamic model has been tested in passing over bumps regime. The dynamic analysis - simulation is performed by using the MBS environment ADAMS of MSC Software.*

Key words: *motor vehicle, axle guiding linkage, dynamic analysis.*

1. Introduction

In relative motion to car body, the rear axles of the vehicles are guided by spatial linkages, on which between axle and car body a number of binary links or kinematics chains are interposed. The links' connections to axle and car body are made through compliant joints (i.e. bushings). To the suspension displacement, the bushing elements undergo elastic restricted linear and angular deformations, the connection allowing in fact six elastic restricted degrees of freedom.

Usually, the theoretical study of the guiding linkages has at basis the symbolical representation of the bushing by a spherical joint, without elasticity, neglecting the linear deformations (rigid joint model) [1], [2], [6], [7]. In this way, the guidance of the rear axle relative to car body is realized by driving a number of its points (three, four or five points) on suitably chosen surfaces and curves (sphere - S, circle - C, coupler curve - CC).

The increasingly growing demand for more comfortable cars imposes a new way for dynamic analysis of the axle guiding linkages, with elaboration of models that are close to the real mechanisms on the car. Involving the deformability in bushing elements, the degree of freedom of the guiding system is increasing and it's practically impossible to analyze such models with traditional methods. Under these circumstances, it is necessary to use mechanical systems analysis software - MBS (Multi-Body Systems), which automatically formulate and solve the motion equations system [4], [5], [8].

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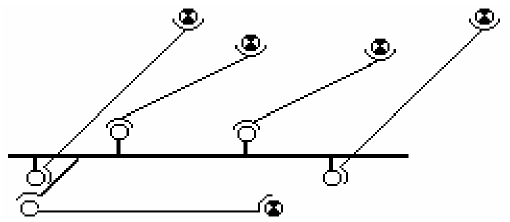


Fig. 1. *The axle guiding mechanism by five points - 5S*

This allows to create a detailed digital model, and to use it in a virtual experiment, in a similar way with the real case. In this way, the dynamic behavior of the system can be accurately predicted.

In this paper, we attempt to study the influence of the compliant joints on the dynamic behavior of a rear axle suspension system. In fact, we are interested to determine the differences in behavior between the compliant model (with bushings) and the rigid model (with spherical joints). The comparative analysis is made by taking into consideration an axle guiding mechanism by five points - 5S type (Figure 1), which has four longitudinal arms and one transversal arm - called Panhard arm (to take the transversal forces). The value of the geometric, elastic and damping parameters corresponds to an off-road vehicle.

The dynamic analysis is performed by using the MBS environment ADAMS (Automatic Dynamic Analysis of Mechanical Systems).

2. Developing and Analyzing the Dynamic Model

The dynamic 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 & rebound elements, and tires).

The suspension system of the rear axle is modeled in the global reference frame (GRF), which is attached to ground. For each mobile part, a body reference frame (BRF) is defined, which is fixed in that body.

The complexity of the guiding linkages of the passenger cars makes it very difficult to handle the error in the case of simultaneous achievement of the entire model (whole vehicle model), and for this reason, in preliminary stages, partial models are tested (for the front wheel suspension or rear axle suspension): quarter-car or half-car models.

For the virtual model of the rear axle system (half-car model), in the lack of the front suspension, modeling a fictive spherical joint between car body and ground, placed in the longitudinal plan of vehicle, ensures the car body equilibrium (Figure 2). The location of the spherical joint has been obtained on the basis of double- conjugate points' theory [3].

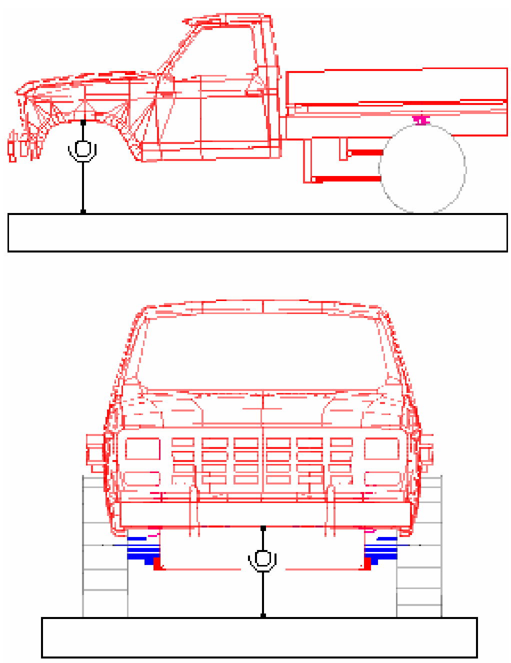


Fig. 2. *The half-car model with spherical joint*

The property of double-conjugate points is that forces applied at one of them produce no motion at the other. Each ends of the car body makes an oscillation about its own conjugate point so that in this point will be placed the spherical joint, respectively in the conjugate front point.

Therefore, the half-car model takes into account the entire mass of the car body, which is concentrated in the front and rear conjugate points. Excepting the car body, the virtual model contains the guiding mechanism of the rear axle, which includes the rigid bodies and the elastic & damping elements.

The five-links guiding mechanism (Figure 3) is a dependent suspension model. 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. Compliant joints (bushings) connect the guiding links to the solid axle, respectively to the car body. Revolute joints connect the axle spindle to the wheel parts.

The solid model of the guiding mechanism was created by using the modeling facilities from ADAMS/View interface. For car body, shell elements create the graphics, which was realized using CAD software environment (CATIA). The geometry was imported in ADAMS using the STEP file format. ADAMS/Exchange reads the CAD file and converts the geometry into a set of ADAMS geometric elements.

The spring & damper group is modeled as a double active (tension-compression) element of translational nature, disposed between car body and axle. The necessary specifications for modeling are: the global coordinates of the points in which the springs/dampers are connected to car body and axle, the length at preload of the spring, the elastic force vs. deflection characteristic, and the damping force vs. velocity characteristic.

The internal forces of the elastic elements limiting the run have transitory character and for this reason these elements have been modeled as translational springs with unilateral rigidity, i.e. which are active only when spring is in tension (rebound elements) or in compression (bumpers), respectively.

The virtual model of the half-car suspension system (Figure 4) is analyzed in passing over bumps regime, using a virtual lab stand. The rear wheels are anchored on two actuators, which execute vertical motion relative to ground. The connections between wheels and actuators are modeled by 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, which is as a force force that has a positive value when penetration exists between two geometries.

The specific ADAMS/Solver module has a geometry engine (namely, RAPID) that is responsible for detecting contact between geometries, locating the points of contact, and calculating the common normal at the contact points. Once the contact kinematics is known, contact forces, which are a function of the contact kinematics, are applied to the intersecting bodies.

To model the contact forces, the following data are necessary: the geometry of the wheels and tire patches; the normal contact force, modeled as an impact function; the tire stiffness, used to calculate the normal force for the impact model; the force exponent - a real variable that specifies the exponent of the elastic characteristic (for a stiffening tire characteristic, $e > 1.0$, and for a softening tire characteristic, $0 < e < 1.0$); the damping properties of the contacting material; the penetration depth, representing the boundary penetration at which ADAMS applies full damping.

The inputs applied to the actuators (tire patches) simulate the road profile. In order to simulate the roll motion of the vehicle, the left wheel pass over a bump that has 80 mm height, and the right wheel runs on smooth surface (Figure 5).

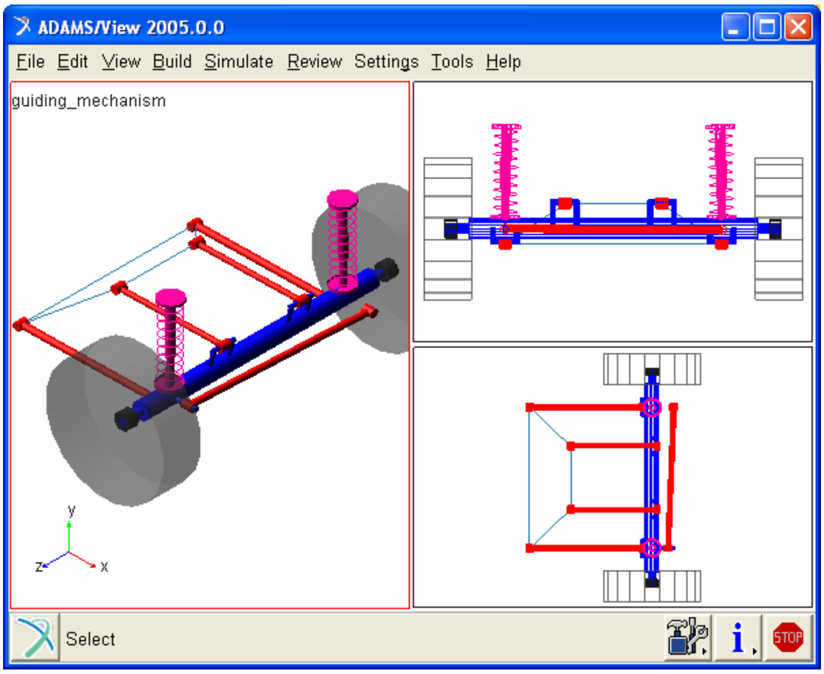


Fig. 3. *The suspension system with five-link guiding mechanism*

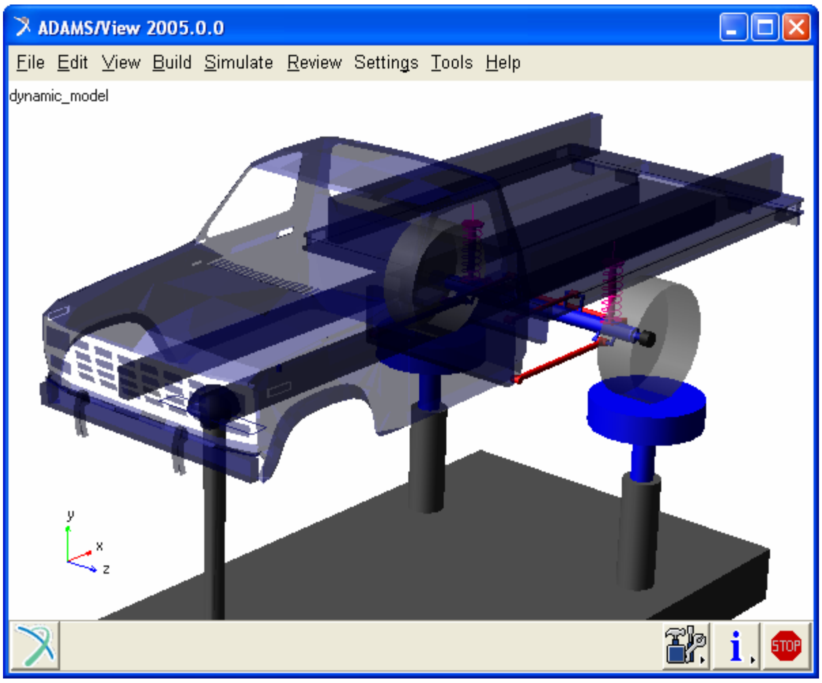


Fig. 4. *The virtual model of the half-car suspension system*

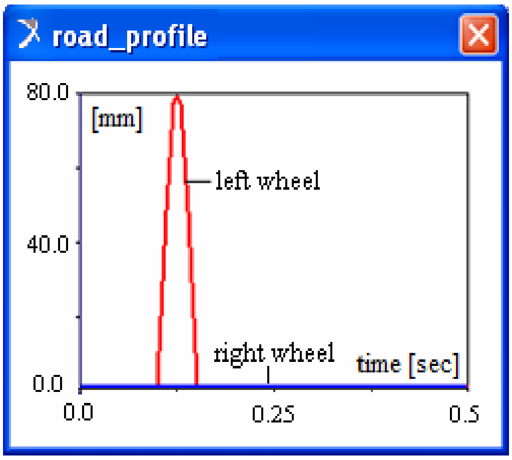
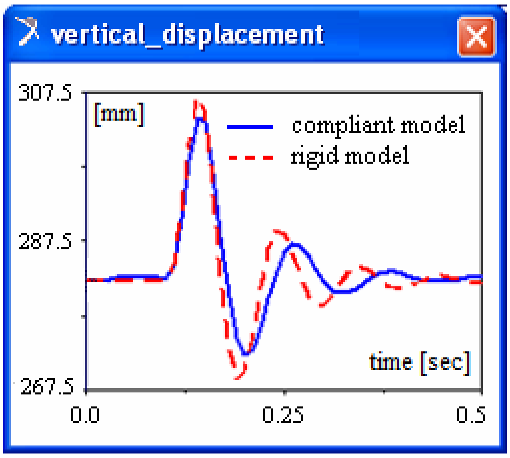


Fig. 5. *The road profile for the left & right wheels*

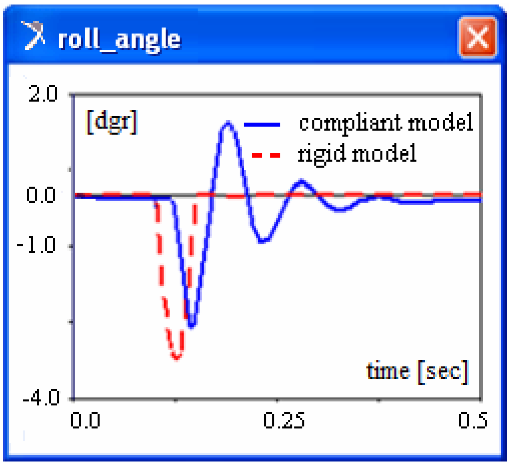
The analysis purpose was to determinate the influence of the compliant joints (bushings with six elastic restricted degrees of freedom) on the dynamic behavior of the suspension system, relative to the rigid model (bushings modeled as spherical joints, with three degrees of freedom).

There are the following parameters used to evaluate the dynamic behavior of the system (Figure 6): the vertical displacement of the car body (a), the roll (b) and the pitch angles/oscillations (c). On the other hand, graphic simulation frames are shown in Figure 7, for the rigid and compliant joint models. In accordance with these figures, the rigid joint assumption is no useful, because there are significant differences between the compliant model and the rigid model, especially regarding the roll motion. The differences are generated by the linear deformations in the compliant joints, mainly the radial deformations.

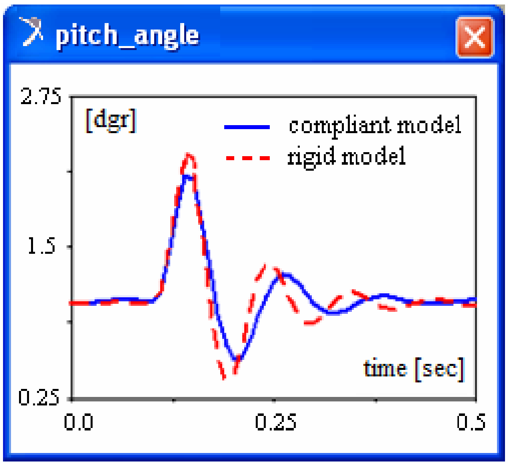
Therefore, in order to obtain a valid virtual model, it is necessary to take into account the deformabilities in bushings; otherwise, the rigid joint assumption generates errors, which denaturize (negatively affect) the dynamic behavior of the suspension system.



a)



b)



c)

Fig. 6. *The dynamic response (behavior) of the car body*

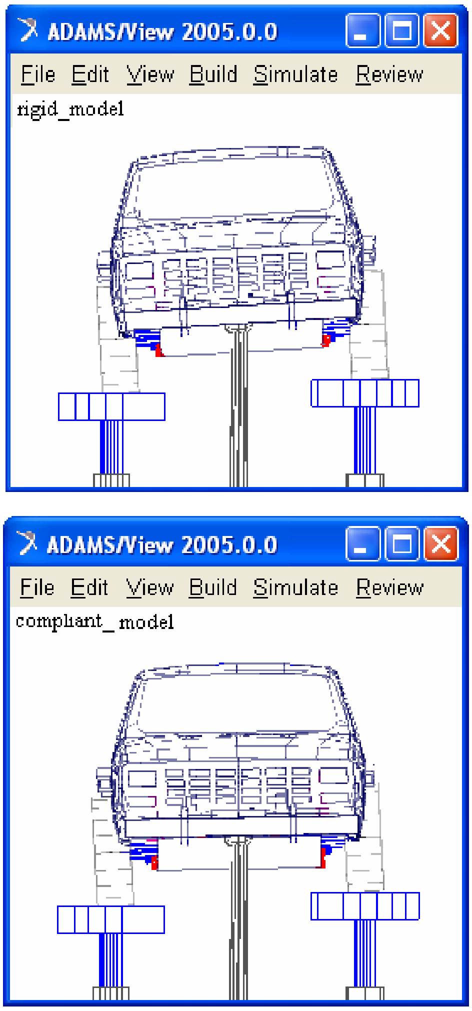


Fig. 7. *Graphical simulation frames*

3. Final Remarks

The modeling and simulation in virtual environment precede the development of the physical prototype, targeting the evaluation of the dynamic behavior. This allows performing virtual measurements in any point and/or area of the guiding system, and for any parameter (motion, force). This is not always possible in the real case due to the lack of space for transducers placement, lack of appropriate transducers or high temperature. Thus, the dynamic behavior of the suspension system may be accurately predicted, without going through expensive physical prototype building and testing.

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