Study regarding the influence of the flexible lamella on the elastic characteristic for a suspension with longitudinal torsion bars

Alexandru Dobre\(^1\), Malvina-Ioana Nedelescu\(^1\), Viorel-Adrian Mateescu\(^1\)

\(^1\)Faculty of Transports, University Politehnica of Bucharest

\(^*\)Corresponding author; E-mail: alexandru.c.dobre@gmail.com

Abstract. A main component of the car suspension is the stabiliser bar, that has the role to reduce the roll oscillations, and it is constructively materializes, within the conventional suspension, via a transversal torsion bar connected direct and indirect between the wheels of the axle. There are constructive solutions of suspensions with torsion bar as elastic element, longitudinal disposed, and that replaces the conventional stabiliser bar with a flexible lamella connected between the ends of the longitudinal torsion bars. So, the flexible lamella has two functions: reduces the roll oscillations and works as an additional elastic element of the suspension. Via this second function it is improved the elastic characteristic aspect of the suspension with positive consequences on the comfort and safety. The paper aims to highlight this influence by the experimental determination of the elastic characteristic of the suspension with and without lamella and the comparing of the two elastic characteristics. It is carried out and a complex theoretical model of the suspension with longitudinal torsion bars and flexible lamella, validated via the experimental research, that allows the optimization of such a suspension.

1. Introduction
When the car moves, the bumps of the road causes wheel oscillations, which are then transmitted to the axles. The suspension establishes the elastic connection through the elastic elements (springs) and the damping elements (shock absorbers), between the axles of the car (unsprung mass) and the frame or car body (sprung mass), having the primary role reducing the dynamic loads and damping the vibrations resulting from the interaction of the wheels with the road. In addition, if the desired character is imprinted to the oscillations, the suspension together the mechanisms of the axle, they influence the stability, maneuverability and handling of the car. The velocity of the car on a particular road is limited firstly by the suspension qualities and then by the engine power.

For good road holding, the tires must be kept in permanent contact with the road surface in order to ensure directional control and stability with adequate propulsion and braking capabilities [1]. The stabiliser bar, as being a suspension component, is used to improve the vehicle performance with respect to these three aspects [2].

The roll center of an axle represents the instantaneous center of rotation of the car body for the roll motion in relation to the road and belongs to the transverse plane which contain the axis of the axle [3]. The roll centers of the two axles define the roll axis, that is, the axis around which the sprung mass (car body) performs the roll oscillation. The reducing the roll oscillation amplitude is an important objective for ensuring the stability of the car and is achieved by elastic connecting the wheels of the
same axle. In usually constructions, this thing is done practically through the stabiliser bar (anti-roll bar).

The torsion bar spring has the shape of a straight bar with the constant section over its entire working length. The bar is requested by the torsional moments generated by the forces applied to the ends of the arm levers. The torsion bar spring character comes from the elastic properties of the material from which the bar is conceived. In order for the torsion bar to have the spring character, it must return to the initial state after applying the torsional moment.

The arm rotates about the axis of torsion bar, and rigidity of the torsion bar and cohesion of damper absorb sudden force change exerted by interaction with the road [4].

The main advantages of the torsion bar spring are: high durability, lowest value for unsprung mass, advantageous loads distribution on the frame, complete absence of internal friction, possibility of adjusting the sprung mass level.

The disadvantages are: the more difficult construction technology compared to the helical spring, disposing on the vehicle more uncomfortable, and more complicated links with the axle, it requires big lengths of work for obtain a high comfort, in case of bar break, the suspension functions are abruptly and totally canceled.

The torsion bar spring is also used as an elastic element of the suspension, can be mounted both transversely and longitudinally, is easily compatible with the articulated axles, is used for both front and rear axles, whether they are drive or non-drive. The longitudinal mounting of the bar has the advantage that it does not impose limitations on the length of the spring, so a more flexible suspension can be achieved. To ensure a good suspension flexibility, in the conditions of a limited value for the bar torsion spring length it is useful to couple the torsion bar with an additional elastic element. If the additional elastic element also fulfills and the role of reducing the roll oscillations, the suspension construction is simplified. A practical solution to achieve this desideratum is to use a transverse elastic lamella (flexible lamella) connected between the fixed ends of the longitudinal torsion bars.

In order for the bars to be torsioned only, they must be mounted on the oscillating axes of the trailing longitudinal arms of the articulated axle, and in order for the wheels kinematic for the suspension debate to be identical for both axle wheels, the lengths of the arms must be equal. Simultaneous fulfillment of these conditions requires an arm to be moved forward with a distance equal to the distance between the torsion bars disposed adjacent, so the wheelbase is slightly different on the two sides of the car [5].

The increasing popularity of sport utility/light-duty vehicles has prompted the investigation of active roll management systems to reduce vehicle body roll. To minimize vehicle body roll and improve passenger comfort, one emerging solution is an active torsion bar control system [6].

There are also and suspensions equipped with stabiliser bars that can adapt their elastic characteristic at the movement conditions, in real-time, called active suspensions. For off-road vehicles moving on rough terrain, the stabiliser bar must be disengaged.

Off-road vehicles are designed with a high centre of gravity due to the increased ground clearance, soft suspension systems and large wheel travel to increase ride comfort and ensure propulsion on all the wheels [7].

The torsion beam is represented as a linkage of lumped mass joined by nonlinear springs, bending and torsion, whose stiffness are identified via off-line computational experiments using nonlinear finite element simulations [8].

Torsion bar suspension systems are applied in all serial main battle tanks produced in Russia (former Soviet Union), the US and Germany, in one type of French and one Japanese main battle tank, and in some British tanks for export as well. All other producers from other countries, whose main battle tanks had the torsion bar suspension, mainly used the license or the experience of the previously mentioned countries [9]. The torsion bar spring (as an elastic element) can also be used as a suspension for electric vehicles where all wheels are of steering [10].

The paper aims to analyze how the transverse elastic lamella influences the elastic characteristic of a suspension with the longitudinal torsion bar of a car by direct measurements on a stand designed and
realized practically. The suspension modeling will be done using the CATIA and ANSYS modeling softwares. The results obtained after the modeling will be compared with those obtained from the experimental determination. Researches on the numerical finite element structural analysis in the transports field was also presented in the papers [11], [12].

2. Experimental research

The stand on which the experimental research was carried out is shown in Figure 1. The stand reproduces the longitudinal torsion bars suspension and the transverse flexible lamella of a car, allows to apply the moment to the torsion bar with applied forces at the end of the axle's lever arm, the measure the displacement of the lever end and the measure the angle of deflection at torsion of the bar. The stand allows the torsion bar to be mounted in two ways:

- the ends of each torsion bar are connected to the ends of the flexible lamella by means of a support;
- the end of a torsion bar is connected by the same support of the stand's resistance structure.

![Figure 1. The general view of the stand](image)

For the left torsion bar, the load is performed by a specific mechanism Fig. 1 and is measured the value of the force applied to the lever end, the lever end displacement and the torsion angle of the torsion bar with the end mounted on the end of the flexible lamella Fig. 2. Repeat the procedure and for the situation where the end support of the tension bar is mounted directly on the structure of the stand Fig. 3.

The results of the measurements are shown in Table 1 and the elastic characteristics of the suspension in the two situations in Figure 4. Comparing the two characteristics, the positive influence of the longitudinal torsion bars on the end of the transverse flexible lamella is noted to improve the flexibility of the suspension.
Table 1. Measurement results

| Torsion angle [°] | Force [N] | Lever displacement [mm] | Torsion angle [°] | Force [N] | Lever displacement [mm] |
|------------------|-----------|--------------------------|------------------|-----------|-------------------------|
| 0                | 0         | 0                        | 0                | 0         | 0                       |
| 2                | 490.33    | 17                       | 2                | 490.33    | 15                      |
| 4                | 882.594   | 31                       | 4                | 980.66    | 29                      |
| 6                | 1323.891  | 50                       | 6                | 1421.957  | 43                      |
| 8                | 1716.155  | 68                       | 8                | 1765.188  | 55                      |
| 10               | 2108.419  | 85                       | 10               | 2108.419  | 70                      |
| 12               | 2451.65   | 104                      | 12               | 2451.65   | 82                      |
| 14               | 2843.914  | 125                      | 14               | 2843.914  | 98                      |
| 16               | 3236.178  | 146                      | 16               | 3187.145  | 113                     |
| 18               | 3530.376  | 165                      | 18               | 3481.343  | 129                     |
| 20               | 3873.607  | 187                      | 20               | 3824.574  | 146                     |

The graphic shows that with the increase of the loading force of the lever increases and its displacement, at the same time amplifying the twisting of the longitudinal torsion bar Fig. 4.
Figure 4. The elastic characteristic of the suspension for the two situations

3. The virtual model presentation

The geometry of the studied system is made using the CATIA V5 software, starting from dimensional parameters measured directly on the experimental stand. For meshing, the automatic generation function is used. The model is then imported into ANSYS software, for to perform the structural analysis. After setting the neutral elements (supports), virtual tests are made, and are registered the results. The description of the completed model is shown in Figure 5.

Figure 5. The stand designed in CATIA software

For development of the model, there were used 3D tetrahedron solid finite elements. The model is consisted of 49248 finite elements and 16286 nodes. The used elements vary depending on the components, as follows:

- for undeformable components, the size of mesh is between 17.45-22.763 mm, with absolute sag between 2.792-3.642 mm;
- for the torsion bars, the size of mesh is 10 mm and absolute sag 3 mm;
- the mesh of flexible lamella is characterized by 20 mm finite elements, with absolute sag 3 mm;
fixing elements as screws and bridles are constituted of finite elements with size between 3.616-5 mm, with absolute sag between 0.3-0.662 mm.
As materials, there is used structural steel for the lever, alloyed aluminum for supports and iron for fixing parts as screws and bridles and usual rubber for nuts. The torsion bars and the flexible lamella are modeled with spring steel; these steels are generally low-alloy manganese, medium-carbon steel or high-carbon steel, with a very high yield strength. For this model, it was used a spring steel with Yield strength of 505 MPa.
The model built in CATIA software is transferred with the corresponding processing in ANSYS program to determine the stresses in the torsion bar Fig. 5. Loading the model with the same forces at the end of the lever arm determines the displacements and the corresponding torsion angles, and the results are presented in Table 2. Based on the results from the Table 2, the elastic characteristics shown in figure 10 are shown. There are considered only static loads analysis.
Comparing the elastic characteristics from the figures 4 and 10 finds that the differences are not significant. The results of modelling on the stresses appearing in the torsion bar are shown in the figures 6, 7, 8 and 9. For example the relative error regarding the lever displacement for an angle torsion of 20° and a force of 3873 N is 1.07% Fig. 7.

| Table 2. Modelling results |
|---------------------------|
|                           | With lamella mounted |
|                           | Experimental        | Modeling          |
| Torsion angle [°]          | Force [N]           | Torsion angle [°] | Force [N] | Lever displacement [mm] | Force [N] | Lever displacement [mm] |
| 0                         | 0                   | 0                 | 0         | 0                       | 0         | 0                       |
| 4                         | 882.594             | 31                | 4         | 882.594                 | 35.878    |
| 8                         | 1716.155            | 68                | 8         | 1716.155                | 71.221    |
| 12                        | 2451.65             | 104               | 12        | 2451.65                 | 101.75    |
| 16                        | 3236.178            | 146               | 16        | 3236.178                | 144.54    |
| 20                        | 3873.607            | 187               | 20        | 3873.607                | 185       |

Figure 6. The lever arm of the axle loaded with a force about 882 N
Figure 7. The lever arm of the axle loaded with a force about 3873 N

Figure 8. The flexible lamella loaded with a force about 882 N

Figure 9. The flexible lamella loaded with a force about 3873 N
Figure 10. The elastic characteristic of the suspension modelled and experimentally determined

For example the relative error (of the value obtained experimentally and the one obtained by modelling) regarding the displacement value of the elastic lamella for an angle torsion of 20° and a force of 3873 N is 2.46 % Fig. 9.

The results validates the developed model and open the possibility of performing a stress test in the torsion bar with a high precision without requiring the experimental tensometric analysis required by the experimental research of the stresses and which is very complex.

4. Conclusions
The flexible lamella has a positive influence on the elastic characteristic of the suspension. The achieved model is validated by comparing the theoretical results with the results of the experimental research. The model can be used for torsion bar stress analysis. The model can be expanded to study tensions and other components of the suspension (flexible lamella and axle (lever arm)). For the small and medium displacements range, the force variation curve determined through modelling is below that determined experimental. At the lever displacement with 40 mm, the force value determined experimental is 1125 N, and the force value determined through modelling is 1000 N, the relative error being about 11 %. At the lever displacement with 88 mm, the forces values are equal and have the 2120 N value. For the big displacements range, the forces values are very similar. For example, at the lever displacement with 150 mm, the force value determined experimental is 3300 N, and the force value determined through modelling is 3380 N, which corresponds to a relative error of about 2.4 %.

The development of the model will allow to determine the elastic characteristic shape and the proportion of the two respective elastic elements, the longitudinal torsion bar and the flexible lamella, for to optimize the elastic characteristic of the suspension at wheel.

References
[1] Hubert, K., Kumar, A., Anti-roll stability suspension technology, SAE Technical Paper, 2005-01-3522 (2005)
[2] Bharane, P., et al, Design, Analysis and Optimization of Anti-Roll Bar, Journal of Engineering Research and Applications, 4, (2014), 9, pp. 137-140
[3] Durali, M., Kassaiezadeh, A. R., Design and Software Base Modeling of Anti-Roll System, SAE Technical Paper, 2002-01-2217 (2002)
[4] Yamakawa, J., Watanabe, K., A Spatial Motion Analysis Model of Tracked Vehicles with Torsion Bar Type Suspension, Journal of Terramechanics, 41 (2004), 2-3, pp. 113-126
[5] Dobre, A., Mateescu, V. A., Axles and Suspensions for Vehicles: Construction and Design (in Romanian), Politehnica Press, Bucharest, Romania, 2017
[6] Cimba, D., et al, Investigation of Active Torsion Bar Actuator Configurations to Reduce Vehicle Body Roll, Vehicle System Dynamics, 44 (2006), 9, pp. 719-736
[7] Cronje, P. H., Els, P. S., Improving Off-Road Vehicle Handling Using an Active Anti-Roll Bar, Journal of Terramechanics, 47 (2010), 3, pp. 179-189
[8] Lyu, N., et al, Design of Automotive Torsion Beam Suspension Using Lumped-Compliance Linkage Models, Proceedings, American Society of Mechanical Engineers, ASME 2006 International Mechanical Engineering Congress and Exposition, 2006, pp. 219-228
[9] Stevanović, R., Characteristics of Torsion Bar Suspension Elasticity in MBTs and the Assessment of Realized Solutions, Scientific Technical Review, 53 (2003), 2, pp. 67-71
[10] Dong, Z., Deng, Z., Design of New Suspension for Four-Wheeled Independent Steering Electric Automobile, Proceedings, International Conference on Electronic & Mechanical Engineering and Information Technology, IEEE, Harbin, China, 2011, Vol. 3, pp. 1130-1135
[11] Popa, A., Scurtu, I. C., Ali, B., Novac, G., Meshing and 3D Modelling for Ship Construction Elements, Scientific Bulletin of Naval Academy, XX (2017), 1, pp. 271-277
[12] Novac, G., Scurtu, I. C., Pazara, T., Simulation of Mechanical Stress Supported by Marine Diesel Engine’s Fixed Parts, Scientific Bulletin of Naval Academy, XX (2017), 1, pp. 267-270