Estimate of elastomer elastic members’ impact on the vehicle ride quality, mobility and reliability in low temperatures

Y. Molev¹, D. Proshin¹, E. Stepanov¹, S. Maleev¹, I. Mavleev² and I. Salakhov²

¹ Nizhny Novgorod State Technical University after R.E. Alekseev, professor
¹ Nizhny Novgorod State Technical University after R.E. Alekseev, head teacher
¹ Nizhny Novgorod State Technical University after R.E. Alekseev, post-graduate
² Kazan Federal University

E-mail: moleff@yandex.ru

Abstract: Tough competition and stringent requirements force car producers to pay special attention to vehicle mobility and reliability in low temperatures. Suspension has a great impact on vehicle mobility and reliability together with tyres being a structural unit protecting the vehicle from the road dynamic effects. Enhancement of these car characteristics is possible by using advanced materials in the suspension structure. Such materials have the necessary strength characteristics, long service life and high resistance to external factors action. Elastomer elements application as suspension elastic-damping members is estimated in the paper. The estimate is based on calculation analysis, mathematic modelling and bench and road test results. A comparative analysis with existing structures has been carried out highlighting both advantages and disadvantages and types of vehicles where elastomers can be most efficiently used have been determined.

Key words: suspension, elastomer, ride quality, mobility, reliability, energy capacity.

Mobility is characterized by the vehicle mass and size, operating and travelling speed, trafficability, manoeuvrability and composure in motion and while running. Mobility is measured by working, transfer and auxiliary operation time [11,16,13].

Reliability is an object property to preserve over time and within certain limits parameters values characterizing its ability to perform the necessary functions in the given application, maintenance and storage conditions.

Suspension is one of the major vehicle assembly units determining a set of performance characteristics—ride quality, composure and manoeuvrability; average and maximum speed, service life of parts and units. All these properties have a considerable impact on the vehicle mobility and reliability as well as on the operator’s ability to drive the vehicle for a long time [6,7,8,9,10].

When designing modern suspensions classical structures with metallic elastic elements (springs, shock absorbers) and hydraulic shock absorbers are often chosen. One of the major suspension properties is the vertical elastic behaviour expressed by the suspension vertical load \( T \) and its vertical strain \( s \) dependence [1,2]. Vertical elastic behaviour parameters are to secure the suspension from breakdowns, roadbed breakaway as well as to provide harshness with the preset accelerations.

Fig. 1 shows typical suspension vertical elastic behaviour, its view and parameters depending on suspension loads in road weight and loaded conditions ratio [2].

Agreed notations in Fig. 1 have the following meanings: \( T_{CT} \) and \( T'_{CT} \) – suspension quiescent loads in loaded and road weight conditions; \( S_0 \) and \( S_a \) – full dynamic actions of rebound and compression strokes; \( S_{OB} \) and \( S_{AB} \) – dynamic actions of rebound and compression strokes from static position to bump stops activation; \( S_s \) – actual suspension static deflection; \( S_{st} \) – assumed suspension static deflection; \( \Delta S \) –
suspension distortion at the application of load to the vehicle from road weight to loaded conditions; \( T_{\text{max}} \) – force maxima working upon the suspension.

\[
C = \frac{T_{\text{max}} \times \omega^2}{g},
\]

where: \( \omega \) – car body over the axis free-running frequency; \( g \) – gravitational acceleration.

Suspension elastic members’ stiffness is a constant leading to frequency rate scattering of the suspension natural vibration rate frequencies in loaded and in road weight conditions. This problem can be solved by the suspension progressive-performance elastic characteristics though it is rather difficult to be structurally implemented.

To meet stringent requirements to the ride quality, composure and manoeuvrability more complex structures with control system and additional units and major components are used for these systems maintenance (air suspension). However such decisions lead to lower reliability rate and fail-and-safe performance of suspension members, increasing structural and operational costs as well. Alternatively, advanced materials can be used to provide the necessary ride quality, reliability, and energy capacity lowering suspension unsprung mass values and increasing the performance characteristics.

**Research objective**

The basic types of suspension are: dependent, independent and semi-independent ones. In the majority of such types either coil springs are used as an elastic element (in light vehicles with independent or semi-independent suspension and in light commercial vehicles) or leaf springs (trucks) [1,2,4,5]. The research objective is to carry out a comparative analysis of suspension structure with an elastomer elastic element and coil and leaf springs structure. The design concept effect on the vehicle mobility, reliability and consumer appeal is determined irrespective of the vehicle purpose.
Research methods
To estimate elastomer elements application as suspension elastic-damping members the following research objectives were selected:

1) front suspension of N1 category light commercial vehicle;
2) rear leaf suspension of N2 category truck.

In the first case the result of substituting a spring as an elastic element for an elastomer packet was estimated. The second case provides analytically estimated results of substituting a leaf suspension for an alternative structure based on the experimental tests of the first object.

Research procedure
GAZelle NEXT A31R33-60 with 3500 kg gross vehicle mass was considered as N1 category light commercial vehicle. To carry out the research front suspension geometrical parameters were studied in order to get suspension performance kinematic picture. Coil spring operational characteristics were obtained being this suspension elastic member. Fig. 2 shows coil spring front suspension general view.

Figure 2. General view of light commercial vehicle front suspension

This suspension is independent, double wishbone, having a double-acting gas-hydraulic shock absorber with a coil spring and a bump stop on the damper piston rod. This bump stop impacts the suspension elastic behaviour at the coil spring high strains. A set of the spring and bump stop joint action brings about the suspension elastic behaviour, therefore the elastomer elements characteristics selection was carried out taking into consideration the spring and the bump stop overall elastic behaviour. It was decided to modify the structure by substituting the coil spring and the bump stop for the elastomer elements packet and to compare the technical performance of the already existing solution and the researched one. Fig. 3 shows the general view of the suspension with elastomer elements.

Figure 3. General view of the suspension with elastomer elements
Fig. 4. shows the suspension elastic members’ characteristics for both design solutions.

![Elastic members' characteristics of the original and the elastomer suspensions](image)

It is evident that the original front suspension structure has piecewise linear vertical elastic behaviour with two elastic stiffness patterns. This is determined by the coil spring and the bump stop. Meanwhile, the suspension with elastomer elements has progressive-performance elastic characteristics and allows to structurally modify the suspension stiffness depending on the load. This feature provides a good ride quality by preserving the carbody natural vibration rate values at different axle loads.

Further comparative analysis of the realized structure with the original suspension revealed the following elastomer suspension deficiencies:
- deterioration in reliability due to complicating the structure by a big number of structure members (elastomer packet guiding structure);
- insufficient damping of the wheels and carbody (refusal of gas-hydraulic shock absorber is impossible at this research stage);
- no considerable vantage of the suspension members’ mass (elastomer packet mass is 4.8 kg, while coil spring mass is 7 kg).

GAZon NEXT C41R33 with gross vehicle mass 8700 kg was considered as N2 category truck. Fig. 5 shows a general view of a rear leaf suspension.

![General view of a rear leaf suspension](image)

This suspension is dependent and comprises the following structure members: main and auxiliary springs, double-action gas-hydraulic shock absorbers and a bump stop mounted on the car frame.
To carry out the research rear leaf suspension geometrical parameters were studied in order to get suspension performance kinematic picture. Main and auxiliary springs operational characteristics were obtained by mathematical and computer simulation modelling. Elastomer suspension structure was designed and a comparative analysis with the original structure carried out basing on calculation and modelling results. Fig. 6 shows a general view of suspension with elastomer members.

Fig. 7 shows an elastomer packet conceptual design map.

Elastomer geometrical parameters selection was carried out by elastomer test in a laboratory environment (fig. 8). Bench tests showed proportionality between the bulk of elastomers and the packet energy capacity (W), necessary for work absorption at the suspension distortion.

\[ W = k \times V \]  

(2)

where: \( k \) – elastomer energy capacity coefficient; \( V \) – elastomer bulk.
Thus, given vertical elastic behaviour of light commercial vehicle and truck suspensions, elastomer suspension structure was designed to substitute the leaf one by energy similarity method. Gas-hydraulic shock absorber with rebound stroke and compression valves was also introduced in the elastomer packet structure. This design solution provides compactability and uniformity of suspension elastic and damping members.

Fig. 9 shows suspension elastic members characteristics for both design solutions.

Leaf suspension structure is characterized by piecewise linear vertical elastic behaviour with three patterns of elastic stiffness. This is determined by the main spring, the auxiliary one and the bump stop. In its turn, the suspension with elastomer members has progressive-performance characteristics and allows to structurally modify the suspension stiffness depending on the load. This feature provides a good smooth ride by preserving the carbody natural vibration rate values at different axle loads. In this case the elastomer suspension advantage becomes evident with respect to weight saving of sprung and unsprung vehicle units. The main and the auxiliary spring mass is 84 kg. Gas-hydraulic elastomer packet mass is 18 kg. Thus, this structure realization reduces the suspension elastic members’ mass by 4.7 times. A set of these advantages provides rationalization for further research in alternative substitution leaf suspensions for elastomer ones.

**Conclusion**

The results of the work show high efficiency of elastomer members in suspensions of N2 and N3 category trucks, M3 category passenger buses as well as specialty vehicles with 4000 kg or more minimum axle load. It is connected to the members’ high energy capacity, resistance to external factors action, non-linear characteristics improving the smooth ride at different vehicle loads, “breakdown-proof effect” at dynamic loads and high reliability of the structure. Using elastomers in light vehicles and light commercial vehicles suspensions is impractical as their structure is complicated by an elastomer packet guiding structure and relatively little vantage of the unsprung members mass.

Besides, using elastomer suspension as an alternative to the leaf suspension allows the following advantages to be realized:

- Improved smooth ride due to the suspension stiffness modification depending on the axle load and reducing the unsprung mass value;
- The suspension cinematics rigidity (absence of drive axle turning at acceleration and braking);
- Decreased dynamic loads on the vehicle units and major components.

Thus, the highlighted advantages improve mobility and reliability of a certain type of vehicles.
Acknowledgement
This work was carried out at the NNSTU named after R.E. Alekseev, with financial support from the government in the face of the Russian Ministry of Education under the agreement 14.577.21.0222 of 03.10.2016. The unique identifier of the project: RFMEFI57716X0222. Theme: “Development an experimental model of an amphibious autonomous transport-technological complex with an intelligent control and navigation system for year-round exploration and drilling on the Arctic shelf”.

References
[1] Grishkevich A.I., Lomako D.M., Avtushko V.P. Cars: Structure, design and calculation. Control systems and undercarriage: College textbook. – M.: Higher School 1987. – 200 p.
[2] Yacenko N.N. Truck smooth ride. N.N. Yacenko, O.K. Prutchikov. - M.: Mashinostroenie, 1968. – 220 p.
[3] Musarsky R.A. Mathematical models of wheeled vehicles: College textbook. – Nizhny Novgorod: Lobachevsky State University, 2008. 164 c.
[4] System dynamics: road - tyre - vehicle - driver / eds. A.A. Hachaturov - M.: Mashinostroenie, 1976. – 535 p.
[5] Rotenberg, R.V. Vehicle suspension / R.V. Rotenberg – M.: Mashinostroenie, 1972. – 392 p.
[6] ISO 2041:2009 Mechanical vibration, shock and condition monitoring — Vocabulary - Third Edition
[7] Mechanical vibration - Testing of mobile machinery in order to determine the vibration emission value; German version EN 1032:2003
[8] ISO 2631-1:1997 Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 1: General requirements (MOD).
[9] ISO 5349-1:2001 Vibration. Measurement and evaluation of human exposure to hand-transmitted vibration. Part 1. General requirements
[10] ISO 5349-2:2001 Vibration. Measurement and evaluation of human exposure to hand-transmitted vibration. Part 2. Requirements for measurement at the workplace/
[11] V Klubnichkin, E Klubnichkin, G Kotiev, S Beketov and V Makarov Interaction between elements of the track ground contacting area with the soil at curvilinear motion of the timber harvesting machine/ IOP Conference Series: Materials Science and Engineering Volume 386, 2018, Pages 012016
[12] A Papunin, VBelyakov, VMakarov, AAnikin and U VahidovA dynamic model of unsupported pit traversal by a vehicle with 6×6 wheel arrangement/ IOP Conference Series: Materials Science and Engineering Volume 386, 2018, Pages 012001
[13] EKlubnichkin, VKlubnichkin and G KotievTheoretical research of soil packing by timber harvester running gear IOP Conference Series: Materials Science and Engineering Volume 386, 2018, Pages 012025