

RETROFITTED REAR SUSPENSION EFFICIENCY

Marijonas Bogdevičius, Raimundas Junevičius

*Vilnius Gediminas Technical University
Transport Engineering Faculty
Department of Transport Technological Equipment
Plytinės g.27, Lt-10105, Vilnius-16, Lithuania
Ph: (+370 5) 274 47 82. E-mail: rj@ti.vtu.lt*

It is popular to retrofit cargo van to passenger mini Bus. Such retrofitting is based on cargo vans, gross weight up to 5t and intended for 10 – 22 passenger seats. Usually the retrofitters in order to improve vehicle ride and passenger comfort are upgrading suspensions. The main aim of this investigation is to compare ride differences of the retrofitted rear vehicle suspension and to evaluate vehicle dynamic characteristic improvement. Three types of a quarter vehicle rear suspensions dynamic models are presented. The first one is a typical cargo van leaf spring suspension, the second most popular retrofitted suspension with additionally mounted air chamber; the third one has modified leaf spring at one end fixed to the vehicle body through an air chamber. As the road disturbance is used speed reduction bump. Mathematical simulation is made with Maple using Runge-Kutta method.

Paper presents variation of the different suspensions natural frequencies; quarter vehicle body accelerations and air spring pressure dependences on natural frequencies of quarter vehicle rear suspension; quarter vehicle vertical body accelerations in respect to time. Dynamic characteristics of all three vehicles rear suspensions are compared and the results are listed.

Keywords: *vehicle, rear suspension, dynamics, numerical methods*

1. INTRODUCTION

Rear suspension structure influences on the characteristics of the vehicle, i.e. not only on comfortable and safe driving, but also on the payload volume in the passenger and baggage sections. Since the space for the elements of suspension is scarce, their layout shall be as compact as possible, but also system shall be functional. Pivot elements of the wheel shall turn the wheel in the direction perpendicular to the direction of the vehicle movement as little as possible (not to increase the rutting). Wheel shall change inclination angle to road surface as little as possible. The durability of joints and wear of tyres are influenced by the positioning of all elements of the suspension. Smooth operation of the suspension elements governs on the kinematical and dynamic characteristics of the vehicle suspension.

Vehicles are upgrading, their driving speed and acceleration increase, therefore, can be lost wheel contact with the road surface, reduced adhesion coefficient and increased the braking distance. High suspension elements speed and acceleration can be a cause of contact with vehicle's body.

In case of improving passengers' comfort in a cabin, safety characteristics are decreased, and vice versa, when the safety characteristics are improved, the drivers and passengers' comfort are decreased.

Comfort and safety arrangement is one of the main problems faced by manufacturers. Over the world minibuses are manufactured by retrofitters or bodybuilders. Retrofitting is usually carried out on the base of a cargo van; therefore, to improve passengers' comfort retrofitters are upgrading parent suspension system.

The most popular retrofitting method among manufactures is to set an additional elastic element, for example, an air spring, into the bus suspension.

In this paper there are compared three suspension systems: the first one is a typical cargo van leaf spring suspension, the second most popular retrofitted suspension with additionally mounted air spring; the third one has modified leaf spring at one end fixed to the vehicle body through an air spring. As the road disturbance is used speed reduction bump. Mathematical simulation is made with Maple program using the third order Runge – Kutta method. All simulation results are listed in a text below.

2. SUSPENSIONS DESCRIPTIONS

Leaf spring suspensions usually are modifying [1], [2], [3], in two ways: one, additional elements are adding into the suspension system; the second, suspension structure is modifying and a new type of leaf spring and elastic elements are mounting. These structural solutions are not

complicated. However, to implement the solutions properly, in the first case, additional brackets shall be mounted on the vehicle axis and the body where the air spring is attached; also additional equipment shall be mounted to keep pressure in air spring. Two, a completely new leaf spring shall be mounted; the body of the bus shall be reinforced since the spring fastening points are changed; possible displacement of the axis shall be limited according to the body of minibus; additional equipment shall be mounted to keep pressure in air spring. The first model Fig. 1 a, b is a typical suspension of basic vehicle on the basis of which modifications were carrying out. Suspensions of this type are using in the vehicles of Mercedes Benz Sprinter, VW LT, Iveco Daily, the gross mass of which does not exceed 3,500 – 4,200 kg. The structure of the suspension is not complicated. It consists of the following: half of the axle mass, mass of the wheel and hub, spring, and a damper.

The leaf spring is fastened to the body by the cylindrical joint at one end. While the vehicle axis moves vertically, this end may revolve only on its axis.

The other end of the spring is attached to the body through an additional cylindrical joint and a rod. The latter structural solution enables to move the end of the spring longitudinally in cases when the spring is deformed (straightened). The vehicle axis is stationary to the spring; therefore, when the spring is deformed, longitudinal wheel displacement occurs. The position of each element is limited by the other components of suspension; therefore, the elements of suspension as well as the whole set of elements may move only in a certain space. This longitudinal displacement is not included in dynamic model so mass m_1 goes only in vertical direction.

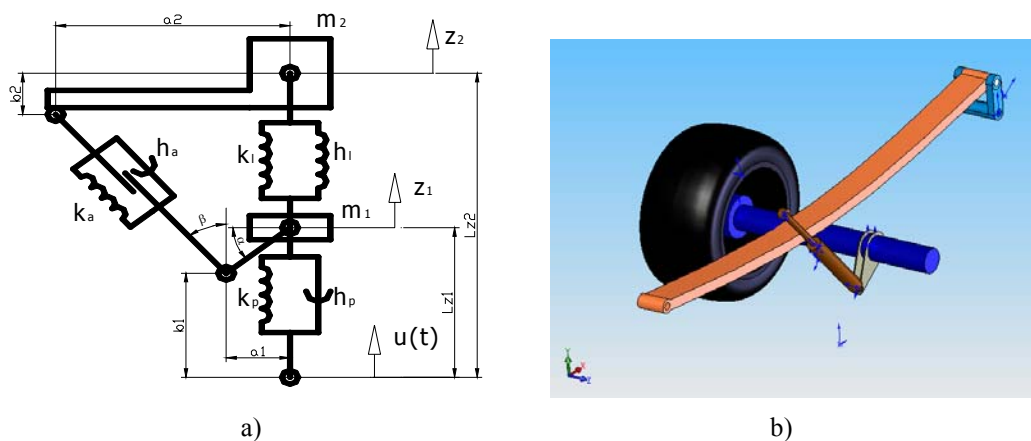


Figure 1. Dynamic a) and the 3d b) models of the first vehicle rear spring suspension

The second structure of the rear spring suspension Fig. 2 a, b is an upgraded structure of the first spring suspension (Fig. 1 a, b). It is comprised of the half of axle mass, wheel and hub mass, leaf spring, damper and an additionally introduced elastic element: air spring, the bottom of which is attached to the rear axis of the bus, and the top is fixed to the body of the bus. The position of each element is limited by the other components of suspension; therefore, the elements of suspension as well as the whole set of elements may move only in a certain space. This longitudinal displacement is not included in dynamic model so mass m_1 goes only in vertical direction.

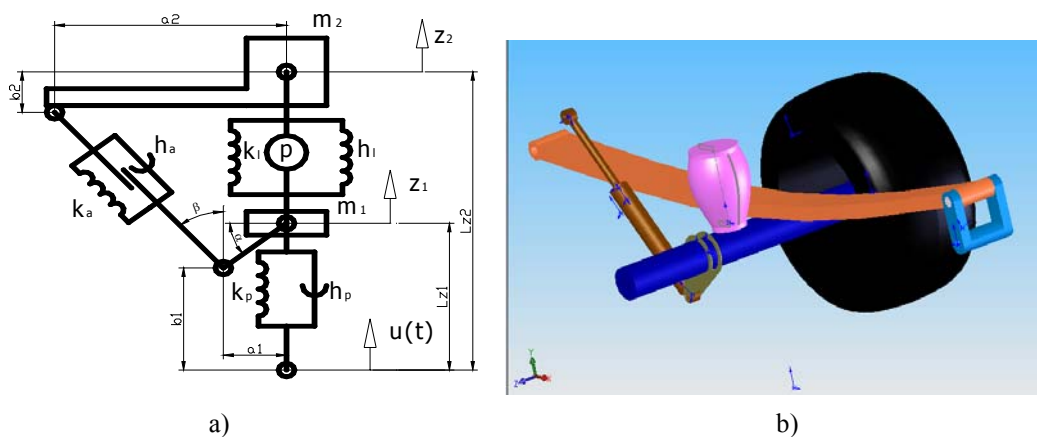


Figure 2. Dynamic a) and the 3d b) models of the second vehicle rear spring suspension

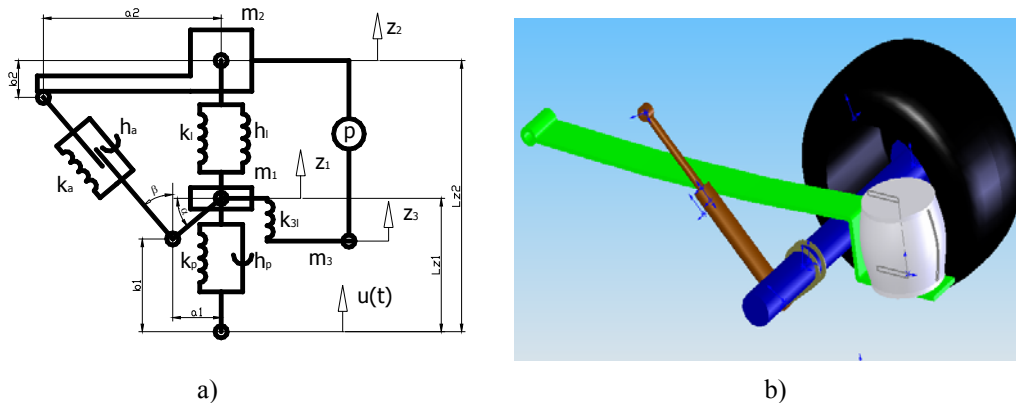


Figure 3. Dynamic a) and the 3d b) models of the third t vehicle rear spring suspension

The third structure of the rear spring suspension is modified first type suspension. This Suspension has new profile leaf spring at one end fixed to vehicle body. Another leaf spring end has a fixation plate for an air spring top of which is fixed to the vehicle body. The position of each element is limited by the other components of suspension; therefore, the elements of suspension as well as the whole set of elements may move only in a certain space. This longitudinal displacement is not included in dynamic model so mass m_1 goes only in vertical direction.

Both modified suspensions models characteristics are compared with traditional van suspension model characteristics (the first case).

3. MATHEMATICAL MODELS

The first model equations:

$$m_1 \ddot{z}_1 = (-c_p \cdot (\dot{z}_1 - \dot{u}_t)) - k_1 \cdot (z_1 - u_t) + F_a - h_l \cdot (\dot{z}_2 - \dot{z}_1) - k_l \cdot (z_2 - z_1) - m_1 \cdot 9,81; \tag{1}$$

$$m_2 \ddot{z}_2 = -F_a - h_l \cdot (\dot{z}_2 - \dot{z}_1) - k_3 \cdot (z_2 - z_1) - m_2 \cdot 9,81; \tag{2}$$

The second model equations:

$$m_1 \ddot{z}_1 = -h_p \cdot (\dot{z}_1 - \dot{u}_t) - k_p \cdot (z_1 - u_t) + F_a - h_l \cdot (\dot{z}_2 - \dot{z}_1) - k_l \cdot (z_2 - z_1) - m_1 \cdot 9,81 - p \cdot S_0; \tag{3}$$

$$m_2 \ddot{z}_2 = -F_a - h_l \cdot (\dot{z}_2 - \dot{z}_1) - k_3 \cdot (z_2 - z_1) + p \cdot S_0 - m_2 \cdot 9,81; \tag{4}$$

$$\dot{p} = \frac{-\gamma \cdot S_0 \cdot p \cdot (\dot{z}_2 - \dot{z}_1)}{V_0 + S_0 \cdot (z_2 - z_1)}; \tag{5}$$

The third model equations:

$$m_1 \ddot{z}_1 = -h_p \cdot (\dot{z}_1 - \dot{u}_t) - k_p \cdot (z_1 - u_t) + F_a - h_l \cdot (\dot{z}_2 - \dot{z}_1) - k_l \cdot (z_2 - z_1) - k_{31} \cdot (z_1 - z_3) - m_1 \cdot 9,81; \tag{6}$$

$$m_2 \ddot{z}_2 = -F_a - h_l \cdot (\dot{z}_2 - \dot{z}_1) - k_l \cdot (z_2 - z_1) + p \cdot S_0 - m_2 \cdot 9,81; \tag{7}$$

$$m_3 \ddot{z}_3 = -k_{31} \cdot (z_3 - z_1) - p \cdot S_0 - m_3 \cdot 9,81; \tag{8}$$

$$\dot{p} = \frac{-\gamma \cdot S_0 \cdot p \cdot (\dot{z}_1 - \dot{z}_3)}{V_0 + S_0 \cdot (z_1 - z_3)}; \quad (9)$$

There \dot{p} – spring air pressure change, γ – adiabatic coefficient, g – gravity constant.

Shock absorber is fixed to vehicle body by cylindrical joint in one end and on another end is fixed to vehicle axel, which can travel only in vertical direction. Dimensions a_1 and a_2 are constant so when vehicle axel travels in vertical direction linear dimension b_1 , b_2 and angular dimension α variation occurs. There dimensions b_1 and b_2 are dimensions from the horizontal road pavement to shock absorber fixing points, α - angular dimension between shock absorber rod and vertical line.

Equation describing starting shock absorber length:

$$L_0 = \sqrt{a^2 + (b_2 - b_1 + z_{03} - z_{01})^2}; \quad (10)$$

There z_{01} and z_{03} starting coordinates. Length of shock absorber is variable so equation 14 has time depending variables $z_i(t)$. The derivative has the second form:

$$L = \sqrt{a^2 + (b_2 - b_1 + z_3 - z_1)^2}; \quad (11)$$

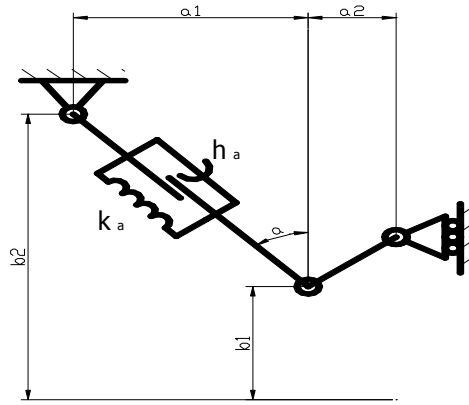


Figure 4. Shock absorber model

Shock absorber length change:

$$\Delta L = L - L_0; \quad (12)$$

Shock absorber length changing speed is described by equation:

$$\Delta \dot{L} = \frac{(b_2 - b_1 + z_3 - z_1) \cdot (\dot{z}_2 - \dot{z}_1)}{\sqrt{a^2 + (b_2 - b_1 + z_3 - z_1)^2}}; \quad (13)$$

Shock absorber damping force:

$$F_1 = c_2 \frac{(b_2 - b_1 + z_3 - z_1) \cdot (\dot{z}_2 - \dot{z}_1)}{\sqrt{a^2 + (b_2 - b_1 + z_3 - z_1)^2}} + k_2 \cdot \Delta L - F_0 \sqrt{\frac{(b_2 - b_1 + z_3 - z_1) \cdot (\dot{z}_2 - \dot{z}_1)}{\sqrt{a^2 + (b_2 - b_1 + z_3 - z_1)^2}}}; \quad (14)$$

Shock absorber tilt angle:

$$\cos \alpha = \frac{b_2 - b_1 + z_3 - z_1}{L}; \quad (15)$$

Shock absorber damping force including tilt angle:

$$F_a = F_1 \cos \alpha ; \tag{16}$$

4. ROAD PROFILE

Road surface is described as speed reduction bump (Fig. 5) [4]. Vehicle moving speeds are: 20 km/h, 50 km/h, 90 km/h;

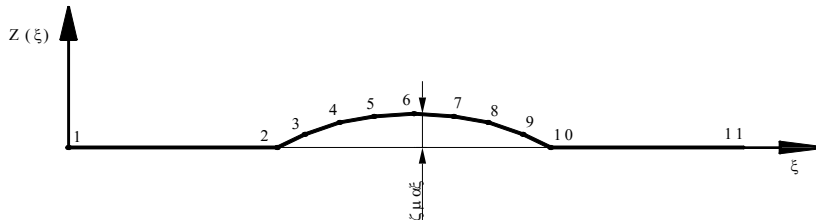


Figure 5. Speed reduction bump profile ($z_{max}=0.05m$)

5. SIMULATION RESULTS

Table 1. The highest amplitude frequencies of suspension characteristic points natural vibrations

Number degree of freedom	Suspension No 1 natural frequencies of vibrations, Hz	Suspension No 2 natural frequencies of vibrations, Hz	Suspension No 3 natural frequencies of vibrations, Hz
1	23,8	23.6	135,8
2	23,8	23.6	135,8
3	2,39	0.00	20,5
4	2,39	2.70	20,5
5	-	2.70	2,03
6	-	-	2,03
7	-	-	0,00

Table 2. Highest amplitudes values of the bus air spring pressure

Volume of air spring, m ³	Frequency, Hz	Pressure, MPa	Scheme No
0,003	2,72	12,568	2
0,03	2,45	1,258	2
0,3	2,42	0,126	2
0,003	2,10	9,379	3
0,03	1,70	1,059	3
0,3	1,60	0,109	3

Table 3. The highest values of the bus body acceleration when the volume of the air spring changes

Volume of air spring, m ³	Frequency, Hz	Vertical acceleration m/s ²	Scheme No
0,003	2,71	0.0653	2
0,03	2,41	0.0539	2
0,3	2,38	0.0526	2
0,003	2,00	0.0396	3
0,03	1,60	0.0294	3
0,3	1,50	0.0281	3

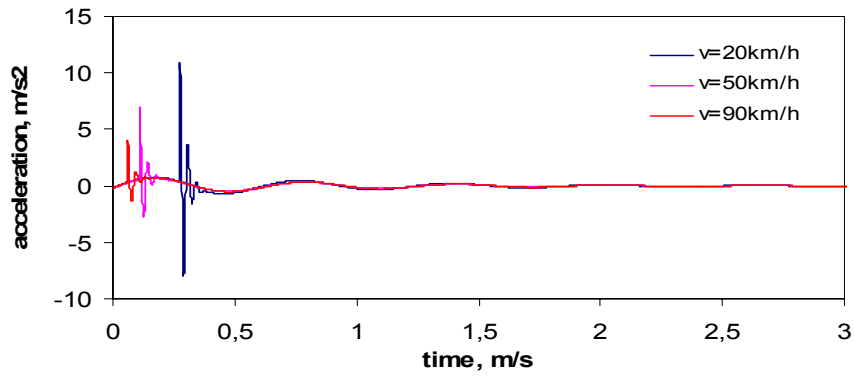


Figure 6. The first suspension model acceleration – time dependence

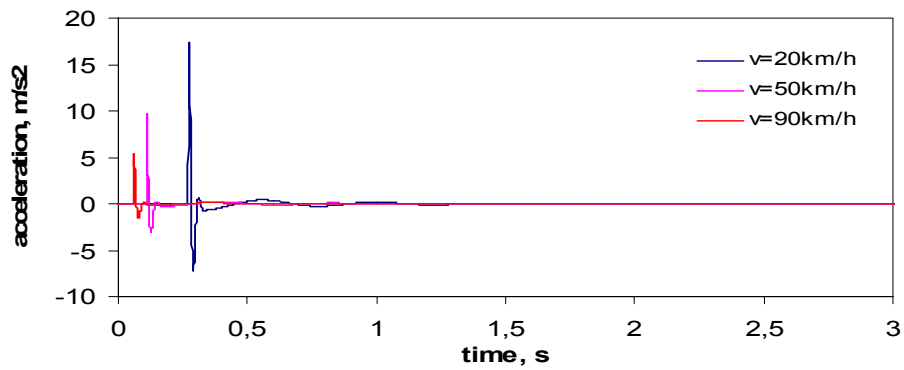


Figure 7. The second suspension model acceleration – time dependence

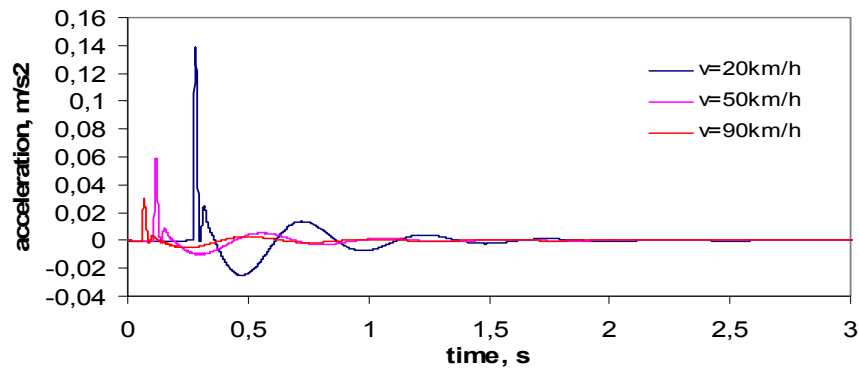


Figure 8. The third suspension model acceleration – time dependence

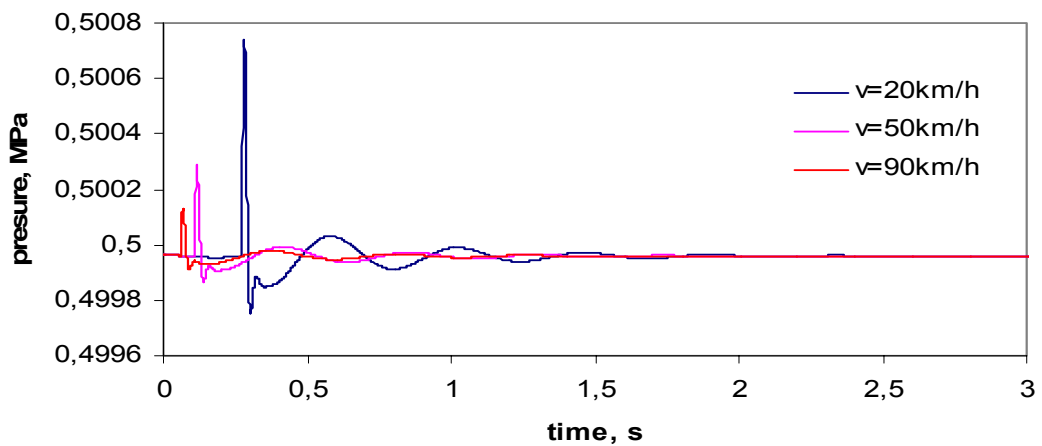


Figure 9. The second suspension model air spring pressure – time dependence

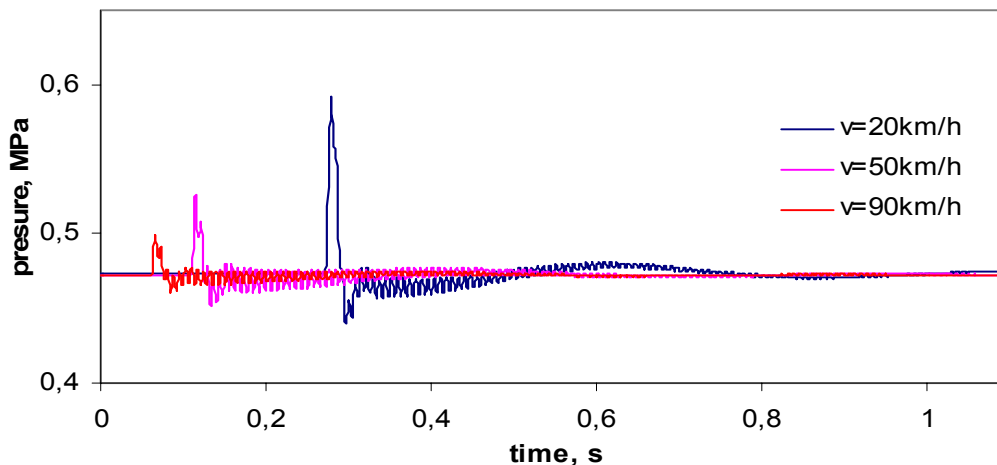


Figure 10. The third suspension model air spring pressure – time dependence

6. CONCLUSIONS

1. Comparing three bus suspensions, there where noticed that the first natural frequencies amplitude of all three suspensions vitiates about 2 Hz. Body acceleration amplitude of the third suspension model and suspension system natural frequencies are lower than the first and the second suspension systems. Results also show that suspension rigidity increasing (the second suspension model) increases natural frequencies.

2. Increasing air spring volume capacity decreases vertical acceleration (from $0,0653 \text{ m/s}^2$ to $0,0529 \text{ m/s}^2$ in the second suspension and from $0,0396 \text{ m/s}^2$ to $0,0281 \text{ m/s}^2$ in the third suspension model) and natural frequency range (from 2,71 Hz to 2,38 Hz in the second suspension and from 2,00 Hz to 1,50 Hz in the third suspension model). All that means that comfort characteristics increases when air spring volume increases.

3. Overcoming road pavement disturbance vertical body accelerations depends on suspension rigidity. The second suspension has the highest-level rigidity so accelerations are topless. The third suspension model has special construction so accelerations are small.

4. Simulation results show that suspension modifications not always are effective. The best retrofitting results are in those cases when suspension system elements characteristics are not the same as in original suspension system.

References

- [1] Bogdevičius M., Junevičius R. Investigation of the Dynamic Processes of the Retrofitted Rear Suspension of the Vehicle. In: *Transport*. Vilnius: Technika, 2004, Vol. XIX, No 6, pp.262-268.
- [2] Bogdevičius M., Prentkovskis O. Simulation of Transport Vehicle Interaction with Road Fence. In: *Transport*. Vilnius: Technika, 1999, No 6 (14), pp. 289-296.
- [3] Prentkovskis O. *Interaction between the Vehicle and Obstacles: Summary of Doctoral Dissertation: Technological Sciences, Transport Engineering (03T)*. Vilnius: Technika, 2000. 56 p.
- [4] Aladjev V., Bogdevičius M. *Maple 6: Solution of Mathematical, Statistical, Engineering and Physical Problems*. Moscow: BINOM, 2001, 850 p. CD-ROM, ISBN 5-93308-085-X.