CORRELATION BETWEEN COMFORT AND ENERGY CONSUMPTION FOR AUTOMOTIVE SUSPENSIONS

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The suspension was developed in order to annihilate the linear oscillations produced by the relative movements of the body car in relation to the wheels on the longitudinal and transversal direction and also the yaw oscillations. The main objective of this paper is to establish a correlation between comfort and energy consumption. The paper will present a new model of an active suspension using the AMESim program, in order to be compared with a standard suspension model. Using the numerical simulation with AMESim language, the authors have developed many models of suspension comparing active or semi-active suspensions with the passive ones.

Keywords: energy consumption, automotive comfort, suspension, modelling and simulation, AMESim.

1. Introduction

The occurrence of vibrations and oscillations leads to the increasing of fuel consumption, because supplementary resistances from the elastic elements of the suspension must be overcome, but also to increased supplementary losses of energy in tires. All these issues are related to the quality of suspension in a large extent, its role being to transform shocks in damped oscillations. The existence of automobile vibrations and oscillations adversely affect the passengers comfort, causing them high fatigue and unpleasant physiological sensations. To improve the passengers comfort, the suspension of automobile has been steadily improved, observing that active suspension can satisfy even the most exigent passenger in terms of comfort. But a substantial increase of comfort with such a suspension increases energy consumption. So, active suspension is especially used in luxury class automobiles. When a car is moving in a congested urban area, about two thirds of the energy stored in the fuel is lost as heat yielded to the walls and coolant. Major energy losses are heat losses, given by the car's engine, losses at idle running and standby, losses by braking, transmission loses, rolling resistance,

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aerodynamic losses and losses through the use of accessories. A significant loss of energy is the vibration’s energy dissipation in the vehicle's suspension system. The vibrations resulting from driving a car on a road with irregularities are usually wasted through conversion into heat. The theoretical researches were compared with experimental ones, made by consecrated companies in the field.

In the scientific literature, there are a lot of studies based on adaptive control methods to improve the properties of the car suspension systems [1-3]. The electronically controlled active suspension systems can simultaneously improve the ride comfort as well as the road handling of the vehicle [4, 5].

Ride comfort is a key issue in design and manufacture of modern cars. Design of advanced suspension systems is one of the requirements, which provide a comfortable ride by absorbing the road disturbances as well as maintain the car stability. A good amount of research activities has been directed to increase the ride comfort especially over the last decade [6, 7]. Modelling of car suspension is of great interest for automotive and vibration engineers. Vehicles ride quality is prime concern for the engineers when a passenger car passes over the speed bump [8].

During the past years a broad interest was registered in the use of advanced control and automation techniques for improving the performance of the vehicle suspension system. The basic purpose of the suspension system is to isolate a car body from road irregularities in order to increase the driving comfort, safety in terms of wear and tear of the car parts, and retain continuous road – wheel contact in order to provide road holding [9, 10]. The active suspension system has great performance of vibration isolation but it consumes extra energy [11].

2. The active quarter vehicle model

The model is composed of two solid masses (sprung mass, m_s and unsprung mass, m_u), stiffness and damping suspension (k_s and c_s), stiffness and damping tire (k_t and c_t) and control part. The model contains two degrees of freedom: the displacement of the sprung mass, z_s and the displacement of the unsprung mass, z_u. It is noted with y the road excitation. The differential equations which describe the movement of the passive model of the suspension are:

$$m_s \cdot \ddot{z}_s = -k_s \cdot (z_s - z_u) - c_s \cdot (\dot{z}_s - \dot{z}_u) \quad (1)$$

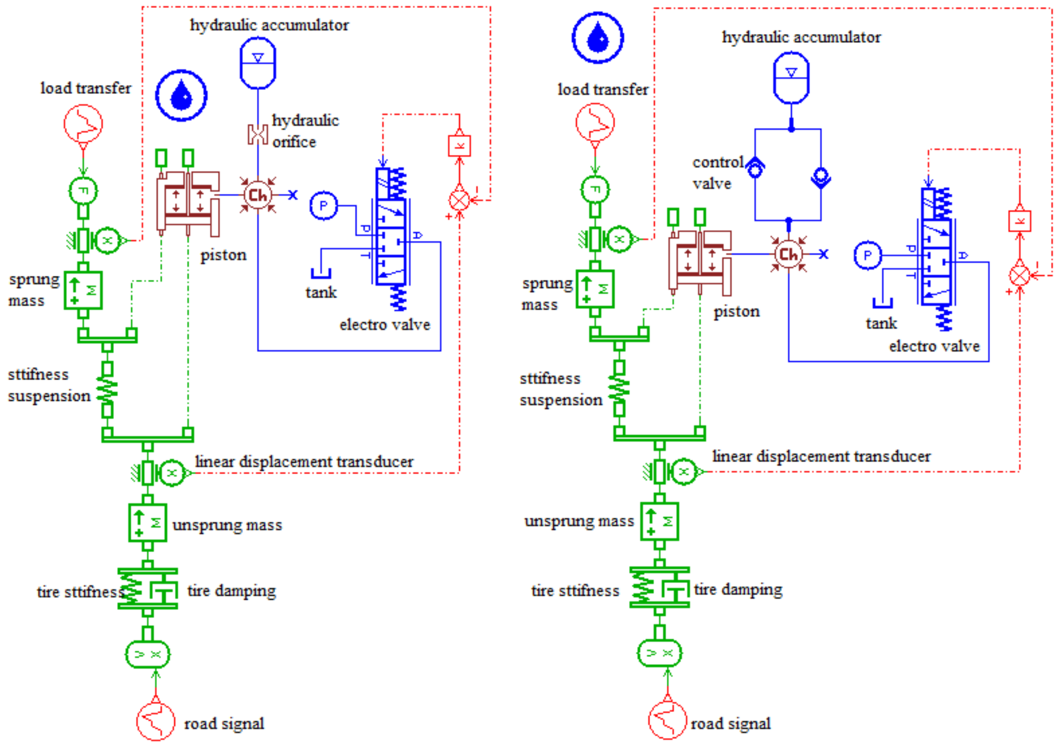
$$m_u \cdot \ddot{z}_u = k_s \cdot (z_s - z_u) + c_s \cdot (\dot{z}_s - \dot{z}_u) - k_t \cdot (z_u - y) - c_t \cdot (\dot{z}_u - \dot{y}) \quad (2)$$

The equations (1) and (2) can be written in a matrix form:

$$[m]\cdot\ddot{z}+[c]\cdot\dot{z}+[k]\cdot z=F \tag{3}$$

$$\begin{bmatrix} m_s & 0 \\ 0 & m_u \end{bmatrix}\cdot\begin{bmatrix} \ddot{z}_s \\ \ddot{z}_u \end{bmatrix}+\begin{bmatrix} c_s & -c_s \\ -c_s & c_s+c_t \end{bmatrix}\cdot\begin{bmatrix} \dot{z}_s \\ \dot{z}_u \end{bmatrix}+\begin{bmatrix} k_s & -k_s \\ -k_s & k_s+k_t \end{bmatrix}\cdot\begin{bmatrix} z_s \\ z_u \end{bmatrix}=\begin{bmatrix} 0 \\ k_t\cdot y+c_t\cdot\dot{y} \end{bmatrix} \tag{4}$$

The figure 1 shows a quarter vehicle model for an active suspension for two variants: with fixed orifice (a) and with valves (b).



(a) - fixed orifice (b) - valves

Fig. 1. The quarter vehicle model for an active suspension for two variants: with (a) and with valves (b)

The compared simulation results of the behaviour of different types of active suspensions for a vehicle quarter model are given in figures 2, 3, 4 and 5. In figure 2 is represented the sprung mass displacement variation in function of time for an active suspension model equipped in two variants: with check valves (red line) and fixed orifice (green line) and in figure 3 is represented the unsprung mass displacement. In figure 4 is represented the sprung mass and unsprung mass velocity depending on the time and in figure 5 the acceleration for both cases.

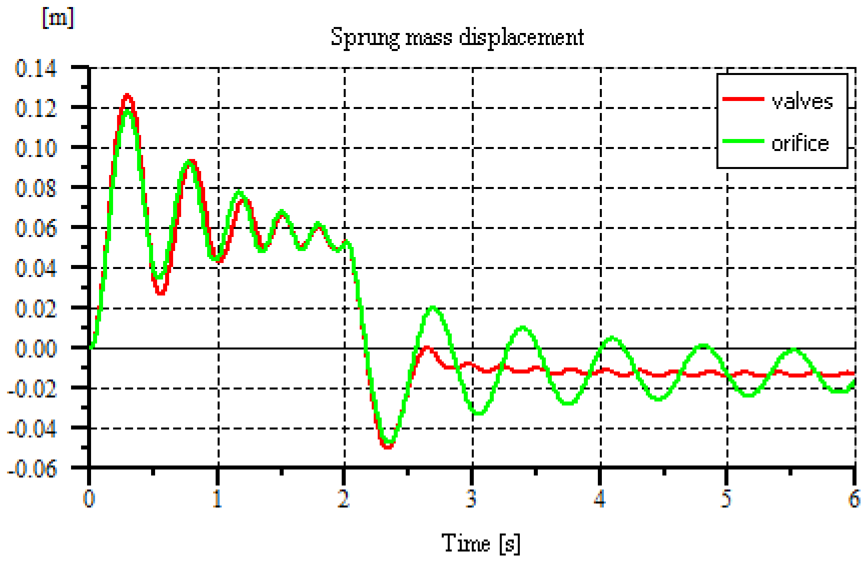


Fig. 2. Sprung mass displacement depending on time

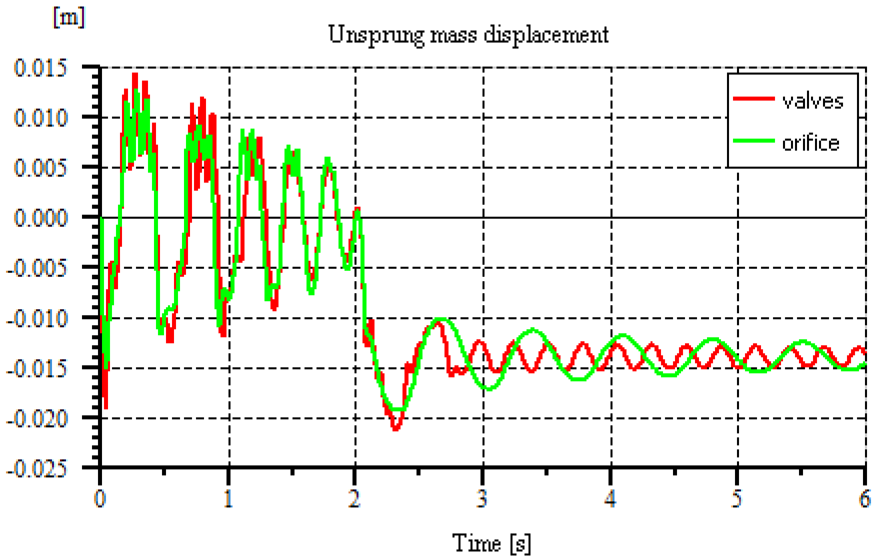


Fig. 3. Unsprung mass displacement depending on time

The control with fixed orifice is not quite satisfactory. This manages to regulate the relative displacement around zero, but on the other hand, the time response is long and the adjustment is very unstable. To obtain a damping more linear the fixed orifice must be replaced by check valves. The simulation results show that the damper's behaviour controlled by a high speed servo valve is not significantly influenced by the fluid's viscosity, but the energy consumption is relative high for a common passenger car. The behaviour of the shock absorber equipped with an orifice depends on the oil viscosity, hence on the environmental temperature. The variant with check valves is more stable than the one with fixed orifice. The active suspension has the purpose to get good performance of vibration reduction with few energy consumptions. The modelling and simulations demonstrated that the control of the active suspension had satisfactory performance in both vibration reduction and energy consumption.

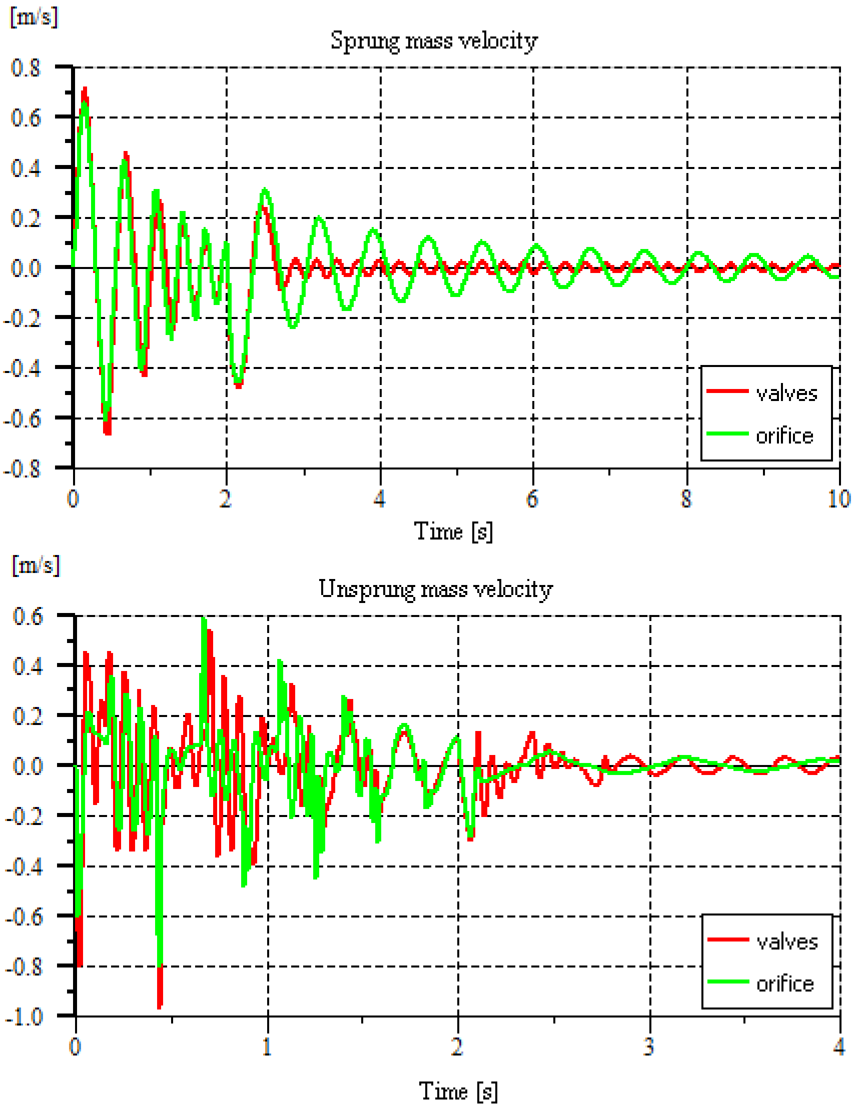


Fig. 4. Sprung mass and unsprung mass velocity depending on time

In order to judge the efficiency of a car suspension, two criteria are commonly used. The first one is the criterion of handling, to see if the wheel follows the road. The second criterion concerns comfort; this is to say the way the body car will insulate passengers from road perturbations. To analyse the comfort, we must look at the vertical acceleration (fig. 5). It imposes low acceleration amplitudes to have a heightened comfort.

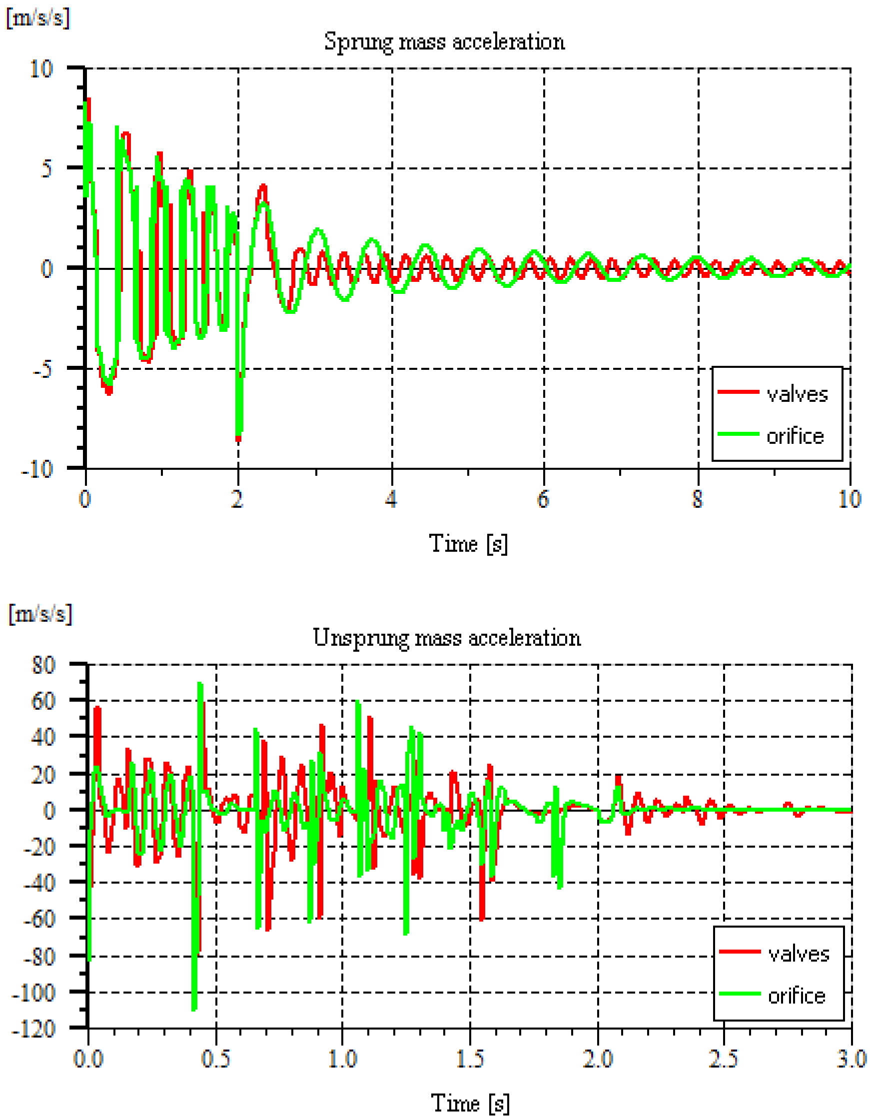


Fig. 5. Sprung mass and unsprung mass acceleration depending on time

The results confirm that the active suspension with valves offers a better control. The time response is the same because, the dynamic of the control valve hasn't changed, and the system is very stable. Figure 6 shows the variation of the flow rate (Q = 2.57 l/min) at the P connection of the electro-valve. Considering the maximum value of the flow rate obtained from the graphic and the constant pressure (p = 70 bar) it can be determined the consumed power (P_c), with the following equation:

$$P_c = Q \cdot p \cdot \frac{0.01}{6} \text{ [kW]}, \tag{5}$$

the consumed power being approximately 0.3 kW.

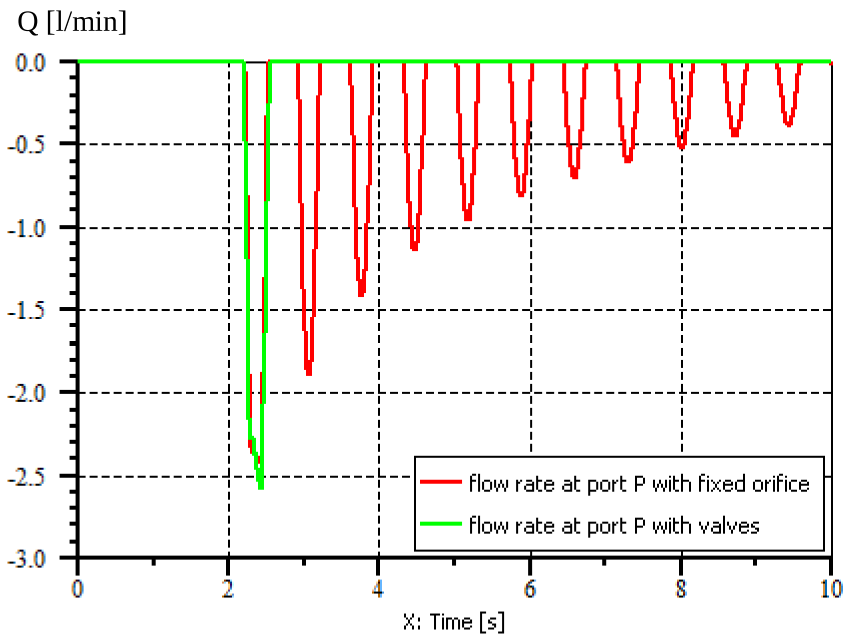


Fig. 6. Flow rate at connection P depending on time

3. Conclusions

The active suspension offers a high comfort and good road holding compared to a passive suspension, but this consistent improvement of the comfort involves an energy consumption. The active suspensions are especially used at the military vehicles, vehicles from the luxury class and sport cars. To benefit the high comfort offered by an active suspension, but with a lower cost, it can be used the semi-active suspension, which changes the damping ratio of the shock absorber. The model can be optimized in order to get a high comfort with minimal energy consumption. The modelling and simulation with AMESim represent the main instrument of study for engineers which test suspensions. The best solution seeing the comfort and energy consumption is the check valves variant. Big companies as: BMW, AUDI, MERCEDES-BENZ preferred the active suspension due to the heightened comfort.

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